Department of Computer Science

Towards a Tangible User Interface for Open Data

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A dissertation submitted to the University of Bristol in accordance with the requirements of the degree of Master of Science in the Faculty of Engineering

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Declaration:

This dissertation is submitted to the University of Bristol in accordance with the requirements of the degree of Master of Science in the Faculty of Engineering. It has not been submitted for any other degree or diploma of any examining body. Except where specifically acknowledged, it is all the work of the Author.

Ashley Elliott Haggan, September 2015

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Executive Summary

Whilst open data is theoretically accessible to anybody, the format is not usable for most people, and most of those that possess the skills to use it are unaware it exists. The aim of this project was to evaluate whether a tangible user interface could allow democratically excluded audiences to be engaged and excited by open data, bridging the gap between open data and the people using it.

The project involved 80% implementation and 20% research. The research drew together the areas of open data and human computer interaction (HCI), to find a relevant area of work where there was a gap. The implementation involved the creation and evaluation of a tangible user interface (TUI) and a graphical (GUI), both used to display open data.

To achieve its aim the project implemented the following:

- A review of the research around open data and current methods of human computer interaction. (Chapter 2)
- A fully working tangible user interface, which displayed open data on a map of Bristol and allowed user interaction. (Chapter 3)
- A Python program was written to read and interpret the open data (JSON) files, accept input from the user and output data to control the interface. (Chapter 3)
- Two Arduinos were used to control input and output devices. Pre-written code was used and adapted for this. (Chapter 3)
- A graphical user interface was created using Java and the Eclipse IDE. This contained a similar map to the TUI and displayed data in a comparative format. (Chapter 3)
- Pilot studies were carried out though the development of the project to help with the design of the interface. (Chapter 4)
- An evaluation between the user experience of the TUI and the GUI was carried out. (Chapter 5)

The most successful elements of the project were as follows:

1. Creating a fully working interface that people like to use.
2. Gluing together a variety of software and hardware to accomplish something that has never been done before.
3. Learning how to use various programs such as Adobe Photoshop and Illustrator to create innovative designs.

Acknowledgements

Because this project was crossed a lot of boundaries between subjects there are many people who I would like to thank for their assistance in getting the project to a successful conclusion. By name I would like to thank:

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There were many other people instrumental to this project's success, from all the engineering and electrical technicians helping with general, almost daily, advice and feedback on the physical form and structure of my project, academics and peers who would offer advice on how to evaluate my project, relevant papers to read and writing tips, through to friends and family who have been kind enough to endure my absence and compromised mood under the pressure of impending deadlines.

Most of all I'd like to thank my lovely wife who is amazing and continues to help and support me in all my endeavours.

Chapter 1

Introduction and Project Aim

1.1 Introduction

Our capacity for measuring and capturing data has increased exponentially with the technology revolution of the last few decades. Governments across the world are opening up their data. The industry value of open data is in the billions. Freely available to be used by anybody, for anything, this information has the potential to address 'societal challenges' (European Commission, n.d.) and empower ordinary people:

> "Access to information networks constitutes the essential tool for enabling citizens to participate in the economic, political, and social life of their communities." (Kvasny et al., 2009, p. 41)

While open data is in theory, accessible to all, in practice the public are mostly unaware, disinterested or lack the skills needed to interpret the vast amount of data available. This results in data that is accessible, but not usable. The main focus of work in this field has shifted from partitioning for more open data to what to do with the open data available. More specifically, how can the data be put into the hands of the people that need it?

Most implementations of open data to date are web-based (Jaakkola et al., 2014) relying on smart phones or computers, and some assume analytic and/or interpretative skills. There is a gap in research into removing obstacles in interacting with open data such as computer literacy and social disadvantage.

This project first looks at an overview of open data and the current issues, examining a representative selection of the ways technology has been used to help people view, interpret and engage with open data. It also explores current methods of human computer interaction (HCI). The research uncovers a need to explore technologies that could bridge the gap between open data and its potential users.

The outcome of this preparatory study is the identification of a potential area that could address some of the issues, mentioned above, through the creation of a novel user interface that would engage democratically excluded audiences with open data and offer a method of interpretation of the data.

A number of interface types were considered, including visual, audio, gesture-based and tangible interfaces, all of which presented familiar interactions to new users. For the purposes of this project a tangible user interface seemed appropriate for the audience and aims. Other interface types could have been chosen on equal merit.

The project focus was on providing a user interface for local open data about residents of Bristol, UK. The data was taken from the 2011 census and relates to the different wards (areas) of the city of Bristol. This data was chosen because the data displayed was relevant to the test participants, as the evaluation of the interface was to be carried out in Bristol. The emphasis of implementation was on democratically-excluded audiences who would not normally be aware of or be able to use this data. This emphasis was considered throughout the design, development and evaluation of the two interfaces.

1.2 Project Aim & Objectives

The aims and objectives of this project were developed in line with the research conducted.

Aim: To evaluate whether a tangible user interface could engage and excite democratically excluded audiences with open data, bridging the gap between open data and the people using it.

In order to achieve this aim, the objectives of the project are as follows:

1. Carry out research of current literature relating to both open data and methods of human computer interaction (HCI).
2. Create a playful, tangible user interface (TUI) able to represent selected sets of open data.
    - The data should be represented directly and ensure no bias or misrepresentation
    - The interface should require no specialist skills to operate or interpret the data shown on the interface. It will be important that any tangible interaction is intuitive and easy to understand. The TUI should not be a barrier, but a conduit, to the data it is representing.
3. Create a graphical user interface (GUI) similar to the TUI.

4. Carry out an evaluation of the TUI, alongside a comparative assessment of the GUI, to provide evidence that it improves users' engagement with open data.

5. Building on the work above, consider suggestions for future work in this area

Chapter 2

Background and Context

2.1 Open Data

2.1.1 Introduction to Open Data

Open data is a radical change in the way that data is accessed and distributed, moving away from previously prevalent proprietary information (Jaakkola et al., 2014, p. 26). The question of who has access to data has profound implications for society. The Open Data Barometer report, produced in 2013, detailed the prevalence and impact of open data initiatives from around the world, and was followed by a second edition in early 2015 which highlighted areas of open data that need to be developed in order to support the Post-2015 Sustainable Development Goals (Davies, 2015). The conclusion of both reports was that Open Government Data has the power to hold governments to account and facilitate action.

> "Questions concerning who has access to data, and whether citizens have the capability and freedoms to create, access, and analyse data about their own communities and concerns, become ever more important for securing a fair balance of power in our societies."(Davies, 2015, p.11)

However, a consistent theme emerges in the literature around open data about the need for the provision of tools and training to allow more people to be able to access this data (Davies, 2015).

Much work has been undertaken in Bristol into the development and release of open data, an insight garnered from dialogue with those involved in open data projects, such as the Future City Manager in Bristol city council, members of the Open Data Institute (ODI) and other professionals interested in this area. One criticism from speaking to local digital and council leaders, is the publication of only 'selected' datasets (Davies, 2015, p.24) - however this not a calculated omission, at least in Bristol; they provide the data most commonly withheld, about government spending. The open data has a cost factor that means the provision of this open data is currently only available for trial periods and in trial amounts.

However, it has been noted that though there has been an uptake of open data for building new products or services, there has not been a concerted effort to use it in addressing environmental concerns, or to increase inclusion (Davies, 2015). It is the latter of these omissions which this project looks to address.

2.1.2 Applications of Open Data

Jaakkola et al. (2014, p. 31) highlights 3 important elements needed in order to use open data effectively:

1) The ability to find the applicable resources (data mining).
2) The ability to use the access interface (API) to it.
3) The technology to apply intelligent data handling methods (Data Analytics).

One observation is the ease in which a person can find the dataset they are looking for; often people need to know where to look or have the ability to effectively search for the data they want. The data is only rendered consumable by users through the provision of an API and Data Analytics. The input is necessary in order to facilitate real access (in this case the ability to interpret data in context rather than in a raw form). Work with open data is now examining the form in which data is provided and not just its provision. The approach taken to points 2 and 3 is the new frontier of open data research, and is the context in which this project sits.

The majority of the growing number of applications that use open data are developed for the mobile platform. Jaakkola et al. (2014) give a general overview of applications created by contestants of open data contests in Finland, all of which focus on the use of open data to provide or improve a service, some examples being local transport and shopping information. These types of contest are common ways that local governments look to promote the use of the open data they provide. Such applications use open data to improve an existing service. In contrast, this project looks to use current technology in order to improve access to and engagement with open data itself.

The majority of new technologies implementing open data use what is called a 'mashup' which, in this setting, is defined as a website or web application that uses content and/or services from more than one source to create a new service. Tim Berners-Lee (2010), the founder of the Open Data Institute (ODI) outlines recent uses of open data after a number of governments started opening their data to the public:

1. The Times Online, within two days of the data appearing, made a map of London containing all bicycle accidents, this allowed commuters to see if their route was affected.

2. A lawyer in Ohio, USA was able to use open data about local housing to highlight racial discrimination of the county.

3. The website wheredoesmymoneygo.org allows people to see where the UK government is spending their money and provides more transparency and accountability for the government from the people it is governing.

4. There was a website set up to help analyse the polling data for the Afghan elections in August 2009 and more recently June 2014 increasing the accountability of this democratic system.

5. Open Street Map allows users to edit map data. Haiti had very poor map data at the end of 2009. After the earthquake in January 2010, Geoeye a commercial satellite company released satellite imagery with an open licence allowing the open source community to edit open street map with this data. This enabled people, who wanted to help, begin to work on the map of Haiti, supplying real time information about refugee camps, blocked roads and damaged buildings. This information was used by relief workers to focus their efforts effectively.

A critical player in many of these scenarios is map provider APIs, which Li & Gong (2008) denote as one of the leading causes in the increase of this 'mashup' technology. In summary, two or more existing technologies are combined in a new format to display existing information in a new way. The focus of this project looks at a novel way to combine current HCI research with open data.

Yokokoji & Harwood (2011) chose a dataset from Bristol city's open data website and used Socrata's API. Socrata is one of the main software companies used to provide access to government data and provides APIs to enable developers to utilise data with relative ease. The API used is called SODA (Socrata Open Data API) and is the same API used on more than 20,000 government data sets, allowing for scalability and transferability of projects. Each open data set has an API endpoint that represents the collection of objects that make up that particular table of data. The data can be queried via the URL used to request the data through the use of a specialised 'Socrata Query Language' (SoQL) which is very similar to 'Structured Query Language' (SQL) which it borrows heavily from. For this project the data was downloaded, as JSON files, and used offline.

Socrata also provide libraries and SDKs for a number of languages including Python, the language that the data management application for the project was written in, so only minor adjustments to the program would be needed to implement this feature. There were no notable APIs used as alternatives to SODA that could have been used alongside local data sets in question.

2.1.3 Interpreting Open Data

Rawlings & Blake (2013) propose that Open Data should include the belief that data should be free of technological barriers. Open data, whilst available, is not in a format understood or usable by most people. Whilst open data has been used for great benefit, it remains those with specific skill sets, knowledge and social class that use and interpret the data. In terms of social class the users, for many of these applications utilising open data, need to own a smart phone and have a good internet connection.

It is an important consideration when looking at designing a new interface for open data that aims to break down some of the current usability barriers, to ensure that the interface is designed to be as user-friendly as possible. The main barriers are the assumption of some computer or numeric literacy to be able to communicate either with raw data or a computer interface to help.

See figure 2.1 for a sample of data represented relatively well against figure 2.2 for a typical, if not slightly better than typical, representation of open data.

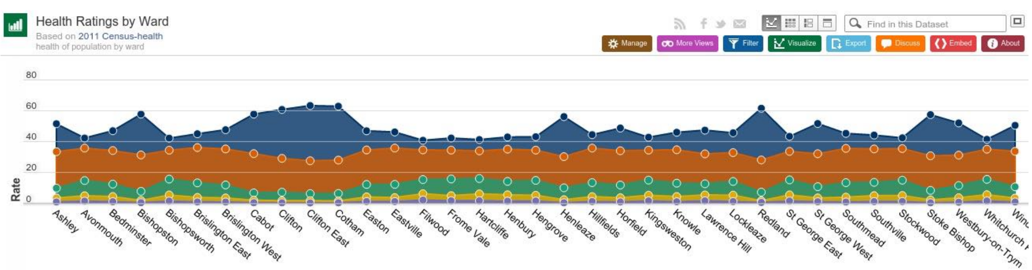
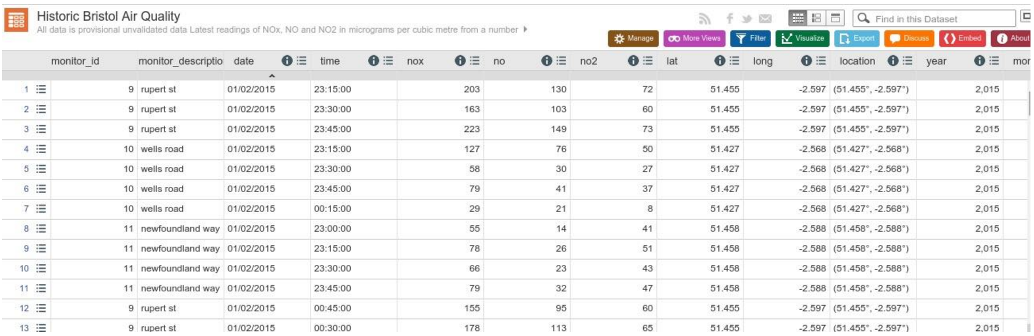


Figure 2.1: Example of data in a more understandable format

These representations of data leave a lot up to the user before they can even think about extracting meaning. Take the example in figure 2.2: what is nox? What is a normal level of nox? Is it good to have more or less?

Microsoft published a report titled 'Using Innovative Technology to Meet the Mandate for Open Data' (Rawlings & Blake, 2013). This article tackles questions around the accessibility of open data, but is mainly focussed on the area of accessibility over usability. In literature about open data the word access or accessibility can sometimes lead to confusion. For example, in this report, the access members of the public have to a weather report, see figure 2.3, is equated to the access they have to open data, which would look something



Historic Bristol Air Quality

All data is provisional unvalidated data Latest readings of NOx, NO and NO2 in micrograms per cubic metre from a number

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	monitor_id	monitor_descriptio	date	time	nox	no	no2	lat	long	location	year	mor
1	9	rupert st	01/02/2015	23:15:00	203	130	72	51.455	-2.597	(51.455°, -2.597°)	2,015	
2	9	rupert st	01/02/2015	23:30:00	163	103	60	51.455	-2.597	(51.455°, -2.597°)	2,015	
3	9	rupert st	01/02/2015	23:45:00	223	149	73	51.455	-2.597	(51.455°, -2.597°)	2,015	
4	10	wells road	01/02/2015	23:15:00	127	76	50	51.427	-2.568	(51.427°, -2.568°)	2,015	
5	10	wells road	01/02/2015	23:30:00	58	30	27	51.427	-2.568	(51.427°, -2.568°)	2,015	
6	10	wells road	01/02/2015	23:45:00	79	41	37	51.427	-2.568	(51.427°, -2.568°)	2,015	
7	10	wells road	01/02/2015	00:15:00	29	21	8	51.427	-2.568	(51.427°, -2.568°)	2,015	
8	11	newfoundland way	01/02/2015	23:00:00	55	14	41	51.458	-2.588	(51.458°, -2.588°)	2,015	
9	11	newfoundland way	01/02/2015	23:15:00	78	26	51	51.458	-2.588	(51.458°, -2.588°)	2,015	
10	11	newfoundland way	01/02/2015	23:30:00	66	23	43	51.458	-2.588	(51.458°, -2.588°)	2,015	
11	11	newfoundland way	01/02/2015	23:45:00	79	32	47	51.458	-2.588	(51.458°, -2.588°)	2,015	
12	9	rupert st	01/02/2015	00:45:00	155	95	60	51.455	-2.597	(51.455°, -2.597°)	2,015	
13	9	rupert st	01/02/2015	00:30:00	178	113	65	51.455	-2.597	(51.455°, -2.597°)	2,015	

Figure 2.2: Example of data in a less understandable format

like the data in figure 2.4, although this might be a kind comparison. Current success of a country's open data provision is seen as good if they have well linked, high quality data sets available on the internet. This is data that is accessible, usable by a computer scientist or mathematician, but not usable to the general public. It would be like giving the public access to raw weather data, much more complex than that in figure 2.4, with no helpful interface or interpretation.

2.1.4 Open Data in the public space

To engage the public who (at least through my experience as a Maths teacher) tend to be turned off by data, any interface or application must engage people, especially if the purpose of the application is to draw attention to the data. In 2011 Yokokoji & Harwood undertook a project called 'Invisible Airs'. This project used the expenditure database of Bristol City Council and converted the amount the government spent on a particular item in the database into air pressure. Five different devices were controlled by this air pressure. These creations engaged the public in a fun and playful way, giving them a tangible interface which they could use to see and feel the data. One approach taken from this work is the idea of the unexpected and unusual in the design of the interface. The downside in these designs however, is the lack of user control. For this project, the interface allows users to chose which data they interpret.

Interacting with data can be an unfamiliar experience for the general public and data visualisations designed for public consumption are still largely under-investigated (Koeman, 2014, p. 173). Koeman (2014) looks at the impact of data visualisation in urban community settings where data was collected from the local community around some prominent local issues. Physical non-digital representations were used to display the data collected. The project concluded that these visualisations made significant steps not only in interpreting the data but in readdressing ingrained views and perceptions. These visualisations

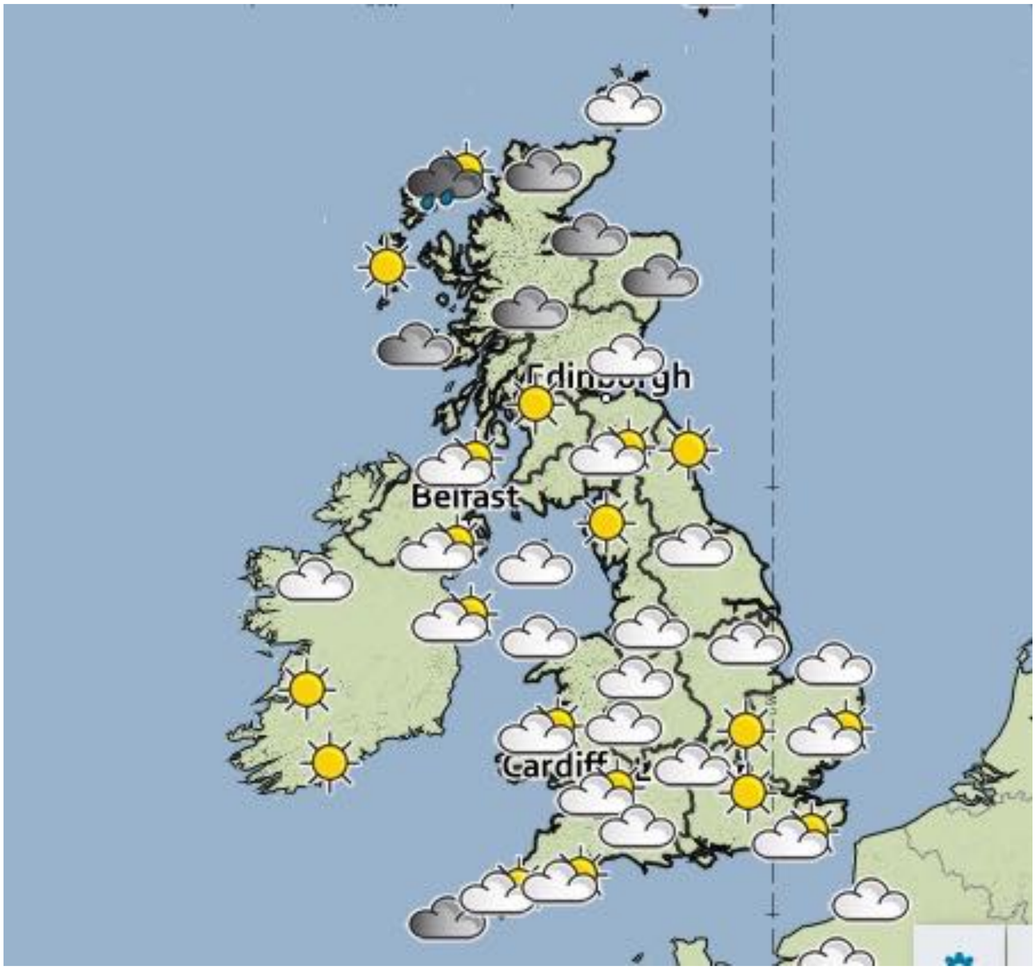

Figure 2.3: Weather Report

left the data to speak for itself. Allowing space for discussion and interpretation of the data was a key aspect in developing an interface for public engagement in this project.

2.1.5 Conclusion - Open Data

Open data is a widening field with many people, agencies and government working on how to best utilise this resource. Developers are beginning to realise the potential of open data. The EU estimates revenue from the provision of open data to be around €40 billion. The common theme that emerges is one of success, however more progress is needed to bridge the gap between the availability of open data and its usability. The project created an

Climate Variable	January	April	July	October	Average
Sunshine (hrs per day)	0.21	0.31	0.35	0.20	0.27
Maximum Temperature (°C)	0.24	0.39	0.49	0.29	0.35
Mean Temperature (°C)	0.26	0.26	0.30	0.25	0.27
Minimum Temperature (°C)	0.39	0.43	0.51	0.47	0.45
Grass Minimum Temperature (°C)	0.52	0.54	0.58	0.60	0.56
30cm Soil Temperature (°C)	0.36	0.44	0.76	0.35	0.48
Precipitation (mm)	13.8	7.4	8.8	12.7	10.7
Days of Rain ≥ 0.2mm	1.22	1.10	1.07	1.17	1.14
Days of Rain ≥ 1mm	0.93	0.81	0.80	0.88	0.85
Days of Thunder	0.27	0.19	0.54	0.20	0.30
	January	March	November		Average
Days of Air Frost	3.37	3.28	2.40		3.02
Days of Ground Frost	5.10	4.97	3.40		4.49
Days of Snow Cover	3.09	3.00	1.72		2.61

Figure 2.4: Refined weather data

interface that intends to alleviate this problem.

2.2 Human Computer Interaction

2.2.1 Interacting with data

The area of human computer interaction (HCI) has much to offer when considering the gap between accessibility and usability of open data.

> "The original and abiding technical focus of HCI was and is the concept of usability." (Carroll, 2014, p. 2.2)

The area of HCI has evolved rapidly since its conception in the early eighties, from the operating systems that led to the era of personal computing through to more recent designs of interactive mobile interfaces such as Apple's Siri, fitness wristbands, smart watches and even Google Glass. HCI is a cross discipline field, and with the availability of easy-to-program hardware such as Phidgets and Arduino it allows not only large corporations, but any individual willing to learn, the ability to create new interactions between themselves, their computer and the world around them. The advent of mobile phone apps or applications has allowed people to design and share their programs "as means for enhancing human activity and experience". (Carroll, 2014, p. 2.3)

HCI is concerned with systems that "fit with people and their ways of living" (Benyon, 2010, p. 6). The hope for open data is that it will be something that people can use to help inform decisions and understand the world they live in. Benyon (2010) talks about the design of interactive systems, emphasising the quality, not only of the physical design, but that of the interactions in the design. These are important aspects of TUI development and thoughtful consideration was taken in how users will interact with the interface.

The familiarity that people have with technology is an important factor to consider when developing new interfaces for a wide, potentially not computer literate, audience. Fortin et al. (2014) looked into community engagement with a digital bulletin board technology and found that "community-related information and content of local relevance rated highest amongst content providers and viewers" (Fortin et al., 2014, p. 1426). These community boards were located in places where they would be noticed and their design and methods of interaction were made to allow familiarity to the users, who were the general public. This allowed for a smoother transition and greater initial user confidence in the new technology. The fact that these boards contained local information relevant to the users gave people a sense of ownership. It is hoped, that by using local data, this project will be able to give a similar sense of ownership and familiarity of access that lets the technology aspect fade into the background and allow people to interact more seamlessly. Ideally, the designed TUI would be located in an accessible place where people have a little time to play with it. This project provided a prototype to assess the feasibility of such an interface, but lacked

Figure 2.5: Old thermostat

Figure 2.6: New 'Nest' thermostat

the resources to be implemented in a public space.

It is important to think about how people might react to a new technology. Yang et al. (2014) looks at how technology is used to promote sustainability in the home. The technology installed was called a 'Nest' and was used to control heating, ventilation and cooling. The paper looks into how the transition is made between the previous manual controls to the new digital interactions. To this end the interfaces used by the electronic controls, in some way, mimicked how their old devices worked, for example using a wall mounted control/display like in Figure 2.6 to replace an old control like in Figure 2.5.
The technology was none intrusive and allowed the user to engage at whatever level they wanted. The hope with implementing this new interface was that people would become aware of how much energy they used and use less as a result. However the new devices needed to work as the old ones did and require little to no interaction with the user. This has a greater level of importance for an interface installed in a person's home, but it is important to consider how people react to new things. Any interface created must offer something for both the person who wants a quick overview and for someone who wants to analyse the data in more detail.

HCI has evolved to be seen as a multi-disciplinary research area with people able to see the impact that computers can have across every area of life. It is under this umbrella that we talk about 'Socially Engaged Arts Practice in HCI'. This paper, written by Clarke et al. (2014), discusses the socially engaged methods that "are increasingly being used within HCI research to understand complex societal challenges" (Clarke et al., 2014, p.69). It could have been a potential weak point for this project to focus solely on the technical aspects of a working interface that displays data and not acknowledge the aesthetic aspects of the design that is ultimately an interface that wants to engage members of the public.

This project will use the notion of human computer interaction to make open data more usable, and to improve what you could call 'human data interaction'.

2.2.2 Types of Tangible User Interfaces

HCI “systems often employ metaphors that give physical form to digital information and are referred to in the literature as Tangible User Interfaces”(Shaer & Jacob, 2009, p. 20::2). It is this type of HCI technology that this project has focussed on developing.

Zuckerman & Gal-oz (2013) conducted a study between TUIs and graphical user interfaces (GUIs) and found that given equivalent performance parameters and better usability of the GUI, the TUI was the, statistically significant, preferred interface of choice for the user. The reasons given were that a TUI:

1. enables physical interaction
2. provides rich feedback
3. produces high levels of realism

This study and others were used in the evaluation of this project in order to provide a basis for comparison of the aspects of user experience found to differ between TUIs and GUIs.

Along with user preference, found in the above study, the familiarity that the physical objects provide was a key reason for choosing this type of interface to implement. An important aspect of this project is inclusion. The way people use and interact with the data shouldn’t be linked to their computer or statistical literacy. Shaer & Jacob (2009) discuss the notion that “TUIs are designed to take advantage of users’ well-entrenched knowledge and skills of interaction with the everyday non-digital world, such as spatial, motor, and social skills.”(Shear & Jacob, 2009, p. 20:2).

As observed by Sindorf et al. (2015) physical objects result in more playful interfaces, which foster engagement better. Sindorf et al. (2015) comment on a number of studies including Horn et al. (2009) and Fails et al. (2005) that investigate the use of tangible over graphical user interfaces, concluding that tangible interfaces are used for longer periods than the graphical equivalent. It is important to note that these studies, whilst highlighting the engagement value of the interfaces, also conclude that there is no evidence to suggest that people learn better through using them. Since the objective of this project is primarily engagement, the issues of usability will be noted, but will not determine the success of this project.

It is important that the ‘playful’ and ‘tangible’ parts of a TUI contain meaning within themselves as well as serving the whole. According to Shear and Hornecker (2010), tangible objects must both ’manipulate and represent’ content. Their paper gives an overview of the past, present and future directions of TUIs and discusses their potential to enhance the way people leverage digital information. This idea of adding further meaning to familiar objects is a common feature of TUI's and was considered when designing components for interaction.

One problem of TUIs is the difficulty in design and implementation. Shaer & Jacob (2009) highlight the fact that most TUIs currently developed are by graduate students. It is likely this has contributed to the fact that there are not many attempts to develop TUIs to help display and interact with data. This offers opportunities for more exploration and novel development opportunities - a positive outcome of this project would be to show the value that a TUI might have in promoting the newly emerging field of open data.

Shear and Jacob (2009) wrote a report outlining 'A Specification Paradigm for the Design and Implementation of Tangible User Interfaces'. Whilst this report is a number of years old, it contains sound principles for the design and implementation of a TUI. The following are potential complications of designing a TUI, laid out in the paper, that this project took into consideration throughout development:

- Designing an Interplay of Virtual and Physical.
- Selecting from Multiple Behaviours and Actions.
- The Lack of Standard Input and Output Devices.
- Designing Continuous Interaction.
- Designing Parallel Interaction.
- Crossing Disciplinary Boundaries.

2.2.3 Conclusion - HCI

The area of HCI offers a range of solutions that could help bridge the gap between accessibility and usability of open data. From this research, a decision to implement a TUI was made and the following considerations were kept in mind throughout development: familiarity of objects used, users' reactions to new technology, the aesthetic aspects as well as the usability and playfulness of the different interactions of the interface.

2.3 Research Conclusions

Whilst there is considerable work around the area of open data, there is a lack of research looking at how to increase the awareness of and usability of this data. Equally there are a number of projects that are incorporating open data in technical projects, but these projects are not officially recorded or evaluated. A gap exists in the crossover of these two areas that offers a opportunity for a novel interface incorporating new technologies to represent open data and be evaluated alongside standard practices of data visualisation. For the purposes of this project, a TUI has been developed in order to address this gap in research.

Chapter 3

Interface Development

The following chapter describes the development of both the TUI and the GUI along with the design and reasoning behind how the interfaces would be evaluated.

3.1 Development of the TUI

Developing the TUI took place in several phases. An agile approach was used, which led to the creation of several prototypes before final implementation. Consequently it was important to be flexible with time and also the order of completion for different tasks. For example, if the interface needed a different part to be delivered, it was important to develop other aspects of the project that might have ideally been developed at a later date. With time and resource limitations put on the project, the final design was not intended to be the best implementation of a tangible display, but a working prototype to be evaluated in order to determine if this type of TUI could offer a solution to the problem with inaccessibility in open data.

3.1.1 Initial Design Ideas

The following section discusses the pros and cons of initial design ideas taken from the research. Some proved fruitful and were implemented in the final design. This section has been included because it was not clear from the research how a TUI using ferrofluid to display data would be built. Since this is a novel implementation it felt appropriate to give a more thorough description of the development process.

Some methods used to replace failed initial ideas came from contingency plans made at the offset of the project. However, due to the variety of skills and disciplines needed to complete this project, some ideas were realised from speaking with academics and experts in various fields such as physics, electrical and mechanical engineering, geography and education. An encouragement to anyone embarking on a similar project is to start making connections and building relationships early, as these are invaluable to the success or failure of cross-discipline projects.

The initial design idea was to place ferrofluid on a map of Bristol and control the behaviour of the ferrofluid using a varying magnetic field, in order to represent data for each local area in Bristol. Each data set in the project would be assigned to a physical object (containing an RFID tag) which, when placed on an RFID reader, would display data from the chosen tag through the magnetised ferrofluid. Each object would be distinctive and would represent the data that will be displayed when this object is selected. Initially electromagnets seemed a good way to attain the variable magnetic field, as this was the method of manipulating ferrofluid most commonly used. There was a need to be able to control sensors and interact with data. In order to do this a micro-controller such as an Arduino, Phidget or Raspberry Pi would be needed.

Ferrofluid

Ferrofluid is a magnetic liquid that conforms to the contours of a magnetic field, but is not itself magnetic. This means that when there is no magnetic field being applied to the liquid it retains a non-magnetized, plain liquid state.

> "The benefits of a magnetic fluid were immediately obvious: the location of the fluid could be precisely controlled through the application of a magnetic field, and the fluids could be forced to flow by varying the strength of this field." (Sileika & Skiedrait, 2009, p. 55)

When looking to create an interactive interface to display data in an interesting and novel way, the use of ferrofluid was an obvious consideration. Initially, the material seemed fun to play with, but too unpredictable to construct something that might display data reliably, and was rejected as a possible option. However, further research revealed projects that had implemented ferrofluids in a precise and controlled manner (not limited to Sileika & Skiedraite (2009), Karunanayaka et al. (2010) and Heng (2011)). The presence of a magnetic field causes the particles to spontaneously orientate along magnetic flux lines, allowing for a big, and unexpected, visual impact to the user. The dynamic and varied visualisation is controlled at will by the position and strength of any number of magnetic fields.

Whilst the use of ferrofluid had the potential to create an exciting and novel visualisation of data, see figures 3.1 and 3.2, it has a number of experimental factors. These areas include, but are not limited to, the density of magnetic particles in the liquid, the surface tension of the liquid, the affect that multiple magnets and varying magnetic field strengths will have and the shape of the magnets. These factors were negated by ensuring only professionally

Figure 3.1: Ferrofluid in action

Figure 3.2: Ferrofluid in action

manufactured ferrofluid was used.

The example most similar to this project was the 'SnOil' (Frey, n.d.) interface, see figure 3.3, which is an interactive interface controlled by a square grid of 144 electromagnets. These are placed directly next to each other and are calibrated so that only the ferrofluid directly above the electromagnet is manipulated by the magnet. Each magnet is individually controlled and is switched on and off via several circuit boards that control the current. This use of multiple electro magnets, in close proximity and independent control, gave confidence that an interface able to represent an interactive map of the areas within the city of Bristol might be feasible.

Figure 3.3: SnOil interface

RFID tags

> "TUIs can incorporate input controls, such as buttons, dials and sliders, as well as other passive or active sensors, bridging the gap between the physical and virtual information." (Simon et al., 2014)

The project will incorporate 'Radio Frequency Identification' (RFID) tags in order for the user to choose the data set to visualise. This technology is used widely from supply chain logistics to unlocking a door at work. As opposed to other common tagging systems, like the barcode, RFID tags do not require visual identification, but they are used with an electronic reader which is able to detect the tags. Other advantages include the ability to both read and write data. This is an important feature for this project in terms of adaptability. If, for example, a different data set needed to be displayed, it would be a simple case of changing the data set a particular RFID tag referred to.

The RFID reader and tags used operated at a frequency around 125kHz. This is low for RFID systems and was chosen because a low frequency has a shorter signal range, which was useful because the RFID tags would often be near each other and relatively near the reader. A low frequency also creates less and is affected less by electromagnetic fields, which meant there was never issues reading the tags in heavily magnetised areas and the RFID reader didn't affect how the ferrofluid was displayed.

Micro-controllers

There are many available micro-controllers that offer similar functionality. The main consumer models are the Raspberry Pi, Arduino and Phidgets. Since the main reason for using one of these was to interface directly with input/output devices, the Raspberry Pi was not chosen, since it has a much slower response time than the Arduiono or Phidget for the devices that were used. Due mainly to the availability of the Arduino, but also due to the extensive open-source software available to run, an Arduino was chosen to interface with the hardware components. The use of the Phidget would have required less understanding of electronics and offers more flexibility and support for a wide variety of languages, however there was a lot of online support for using an Arduino for controlling a variety of input/output devices. The Arduino uses a subset of the C++ programming language which was familiar, and most software needed had already been written and was open source.

Electromagnets

Before starting any investigation of my own I assumed electro-magnets would be the best way to create a variable magnetic field.

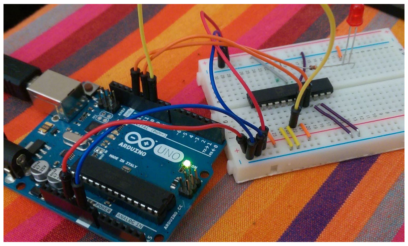

Figure 3.4: Digital Potentiometer

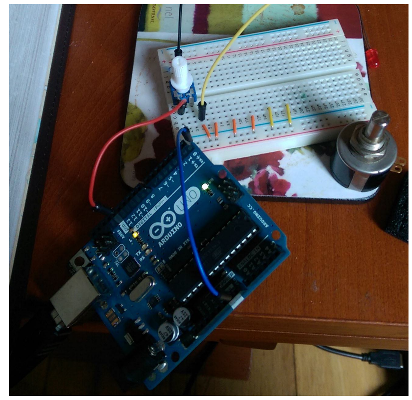

Figure 3.5: Physical Potentiometer

3.1.2 Experimentation of Design Ideas

Once an Arduino board and initial components were acquired there began a significant period of experimentation with various hardware components. See a detailed list of the final components used in the appendix.

Electromagnets

One of the first areas of experimentation was creating a variable magnetic field. The Arduino board was connected to a circuit involving both a digital potentiometer, see figure 3.4, and a physical potentiometer, see figure 3.5. This was done in turn not simultaneously in order to confirm the digital potentiometer was working correctly. Both circuits were also tested with an LED as an easy visualisation of the varying current.

Once varying current was established this was combined with an electro-magnet. This electro-magnet could be varied, but the magnet, when tested on an allen key, seemed to have little to no magnetic effect until it was receiving the full current from the circuit. However, in order to test this further a needle was tied to a piece of string and a slight change in the magnetic pull could be observed, see figure 3.6 and figure 3.7. It was important at this point that some investigation with ferrofluid took place in order to determine if the magnetic field provided by this electro-magnet would be sufficient to manipulate the ferrofluid.

The effect of an electro-magnet connected directly to a 9V battery drawing around 120mA left a lot to be desired, see figure 3.8. Due to the insufficient magnetic field generated by the electromagnet, advice was sought from an expert as to if and how it would be possible to produce the effects seen by the permanent magnet. It was confirmed that this would be possible, however for an electromagnet to produce a stray magnetic field, which is what

Figure 3.6: Smaller Field

Figure 3.7: Larger Field

Figure 3.8: Electromagnet with Ferrofluid

the ferrofluid aligns to, like the one produced by a permanent magnet, a very flat electromagnet like that in figure 3.9 would be required, as opposed to a regular shape, seen in figure 3.10. The flat shape is more difficult to create and a large current would have to be induced to produce the stray field lines seen in a permanent magnet. It was advised that without significant electronics experience it could be very dangerous producing the kind of fields necessary. In order to have an electromagnet producing a force of around half a Tesla, like the permanent magnet used, a liquid cooling system would need to be used to allow the electromagnets to operate for sustained periods of time.

Development of a complex system as outlined above was deemed outside the scope of this project, and the decision was made to go with the contingency plan and use a permanent magnet. The permanent magnet required a mechanism to enable movement of the magnet, and in turn, the magnetic fields, to be adjusted programmatically. Further work determined the best magnet for the job.

Figure 3.9: Flat Electromagnet

Figure 3.10: Regular Electromagnet

Ferrofluid

The next stage was experimenting with the ferrofluid. Ferrofluid is a stable colloidal suspension of super-paramagnetic iron oxide nano-particles (Howto, 2014). The outworking of this is a magnetic liquid that will adjust its form to take on the shape of stray magnetic field lines. There are a variety of factors that affect this shape (including Van der Waals force, magnetism, surface tension and gravity). For this project magnetism was chosen as it is the only variable that could be changed, with relative ease, as a user interacts with the display.

The purpose of the data visualisation was to engage a demographically excluded audience. With this in mind it was important that the visualisation was significantly different enough from usual methods of data visualisation, such as charts or graphs. This is what led to the use of ferrofluid to make a tabletop display in the first place. Ferrofluid is a relatively unknown substance and it's use in displays has little to no documentation, particularly the use of its visual characteristics. There are a couple of displays; SnOil and Mudpad that use the magnetic rigidity properties of ferro fluid, SnOil for its visual effect, see figure 3.3, and MudPad for touch, see figure 3.11. Heng (2011) used ferrofluid to allow tangible user interaction using a wand to create ripples in the ferrofluid and produce sounds, see figure 3.12.

Due to the plain state of the ferrofluid in its de-magnetised form and its striking structure otherwise, this material was chosen for the dynamic visualisation of data. Although outside the scope of this project, the fact that it becomes semi-rigid when in a magnetic field could also allow users to gain a touch sensation from the displayed data.

It was important at this point to observe what strength of magnetic field was needed to give the desired effect and what the ferrofluid looked like as a magnetic field was varied. See figure 3.13 to figure 3.18 to see the change in the ferrofluid when a neodynium magnet

Figure 3.11: MudPad: Localised haptic feedback on a touch surface.

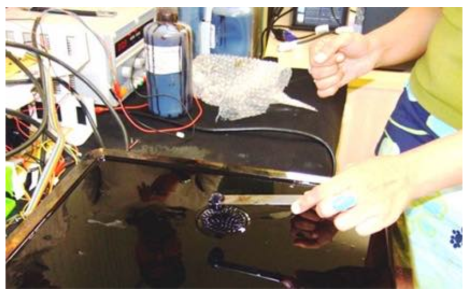

Figure 3.12: When Sculptures Sing: Through new 3D Interface Technology.

with a 2cm diameter is brought towards the surface. The gradual change is what would be used to represent the data.

Multiple strengths and sizes of neodynium magnets were tested with the ferrofluid, from the 2cm diameter magnet, used for figures 3.13 to 3.18, to much larger 50mm x 50mm x 25mm magnets. Neodynium magnets are a type of rare-earth magnets and are the strongest commercially available permanent magnets. The ferrofluid was affected more significantly by a larger magnet, but the shape of the magnet made a smaller difference, square and round magnets both created circular magnetic field patterns until the magnet was almost touching the container the liquid was in, see figure 3.19. In pursuit of the best visual effect, the largest magnets were used, see figure 3.20 to 3.25.

Physical Movement of Magnets

Vertical motion for the magnets was required and so some form of lift mechanism was envisaged, using components that could be controlled by an Arduino. Initial design ideas were thought of in conversation with an engineer, two involving servo motors and one involving a stepper motor, see figures 3.26, 3.27 and 3.28. The latter of these designs, using

Figure 3.13:

Figure 3.14:

Figure 3.15:

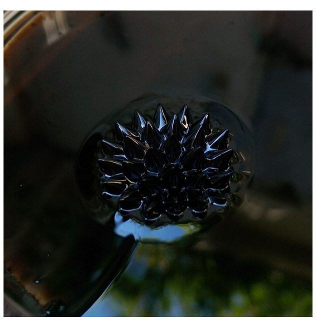

Figure 3.16:

Figure 3.17:

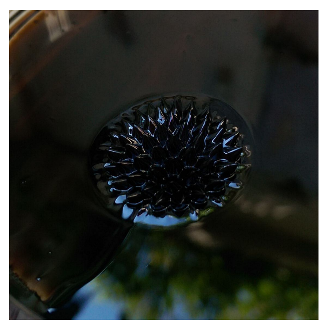

Figure 3.18:

Figure 3.19: Square magnet in contact with the ferrofluid and therefore showing the magnets shape.

Figure 3.20:

Figure 3.21:

Figure 3.22:

the stepper motor, was taken from the mechanism used on 3D printers. I decided against this design due to the need for a sensor to calibrate the height of the platform. Since the stepper motor rotates several times in order to move the platform over a distance it is not possible for a program to know the precise location of the platform when starting the program without a sensor or carrying out manual calibration on each use.

Out of the first two designs the lever model was chosen initially because it had the least intricate parts and would be the easiest of the models to build a working prototype for in order to assess the viability of this method. The first prototype was made with parts gathered from a model shop and cut out and built with only a craft knife and screwdriver. This model, see figure 3.29, was very basic, however the prototype would move up and down as instructed by an Arduino micro-controller. It could lift very small/light objects but would need to be far more robust in order to carry the magnets chosen for the display.

Figure 3.23:

Figure 3.24:

Figure 3.25:

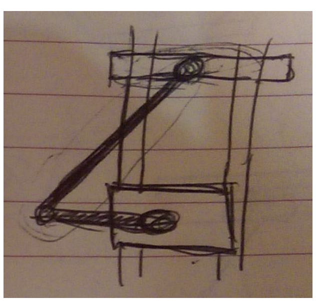

Figure 3.26: Arm and Lever Design

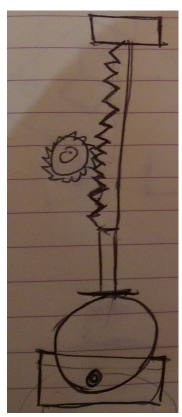

Figure 3.27: Rack and Pineon Design

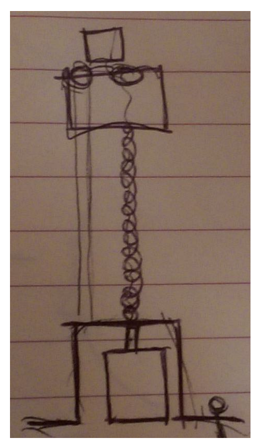

Figure 3.28: Stepper Motor Design

With the initial success of this first prototype, the design was developed through the use of 3D printed and laser cut components in order to give more robustness to the system, see figure 3.30 . The servo was moved to the back so that the lift was generated more centrally to the platform and struts were added as a support for the contact with the legs. Both of these additions helped steady the platform. This caused problems with extra friction leading to the servo drawing more current to push the platform up and down. This was due to the tolerances that needed to be allowed for on both the 3D printers and laser cutters. Further development was still needed to iron out potential issues that could arise later when introducing different size magnets to the lift, plus running several towers at once.

Since the 3D printers took a long time to print the required objects and the tolerances, the measurements required to those produced varied slightly between the machines. A redesign was carried out to make a model that required only laser cutting. This was a lengthy process to get right, but with a working prototype in hand the time was spent to reduce production time and therefore allow for any minor, or major, changes to be carried out quickly. Again there were tolerances to take into consideration, see figure 3.32, but once these were determined and entered into the designs no further adjustments were needed. The final design was a combination of the initial prototype and the rack and pineon design. The problems with friction were reduced and the design was quick to reproduce, see figure 3.33 for the final design and figure 3.34 for the laser cutter design (Each Laser cut design, made from 6mm MDF, would make 2 towers, with the addition of laser cut 5mm thick acrylic cogs which allow the movement).

Displaying the Ferrofluid

Initially the ferrofluid was experimented with in a 3D printed container, see figures 3.20 to 3.25. This worked for a while, but after a few days the container started to leak. This wasn't helped by the continued use of a magnet attempting to pull the ferrofluid through the base of the container, but since this is what the interface would be doing most of the time this couldn't be avoided.

A glass blower was consulted about a design that could contain the ferrofluid whilst allowing users to see it. In order to see the represented data more clearly a curved, dome-like, base was devised, see figure 3.35, that would potentially allow users to see a difference in the data values as the ferrofluid was drawn up the side of the dome, where the fully covered dome represented 100% and no spike would represent 0%. This design worked well, but was prone to discolouration and very costly. Some makeshift attempts at getting the same effect, using empty wine bottles and cheap glassware, were tried unsuccessfully.

The most promising available method to replicate a similar effect was vacuum forming.

Figure 3.29: First Prototype

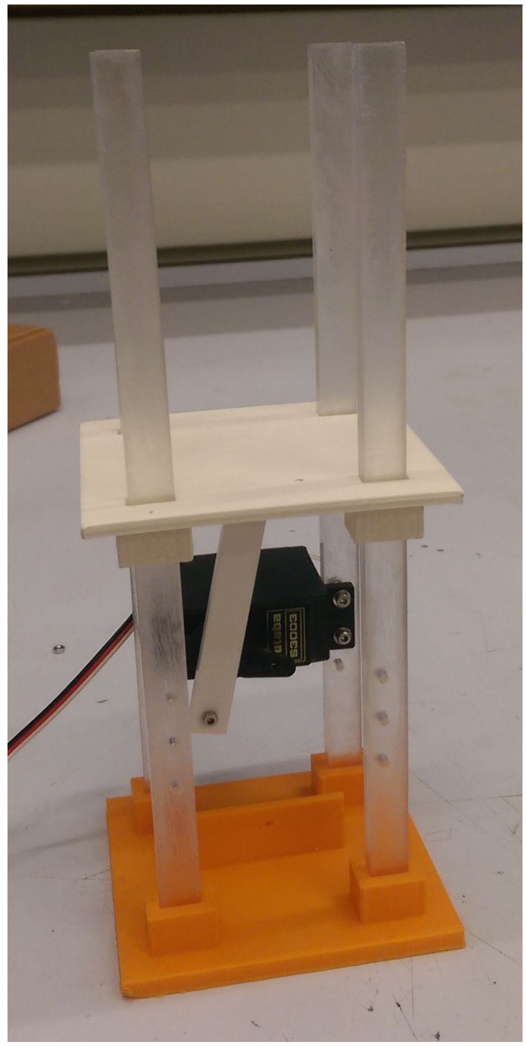

Figure 3.30: Second Prototype

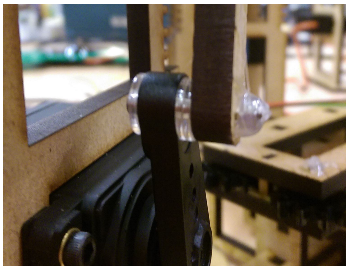

Figure 3.31: Improved quality and robustness of mechanisms

Figure 3.32: Negotiating varying tolerances to apply to the model designs

This took time to get the appropriate access, training and risk assessments, but was an ideal solution to the the problem at hand.

After a number of attempts a successful vacuum form was made and a trial run was completed with the ferrofluid. Whilst the dimensions were theoretically the same as the dome it was clear that the dome needed to be shallower, allowing the magnet to protrude less into the dome itself, see figure 3.36.

Typically the last model tried was the most successful and around 15 vacuum form moulds were made to fit into the map of Bristol. This was to ensure that at least 8 of them would be suitable. The vacuum forming machine was old and didn't create uniform shapes each time. A makeshift press was needed to give the vacuum former some precision, see figure 3.38 for an example of the final dome design working.

3.1.3 Final Design

The following section will discuss the final design and implementation of the TUI.

Visual Design

Bristol has 35 separate wards (areas). To avoid having to negotiate the logistics of a more intricate map design and data display, for both the TUI and GUI, these areas were combined in order to produce a map of Bristol containing fewer (14) bigger areas as opposed to the large number of smaller ones. This allowed for a concise design focussed on the comparison of the two interfaces instead of the added complexity in making them.

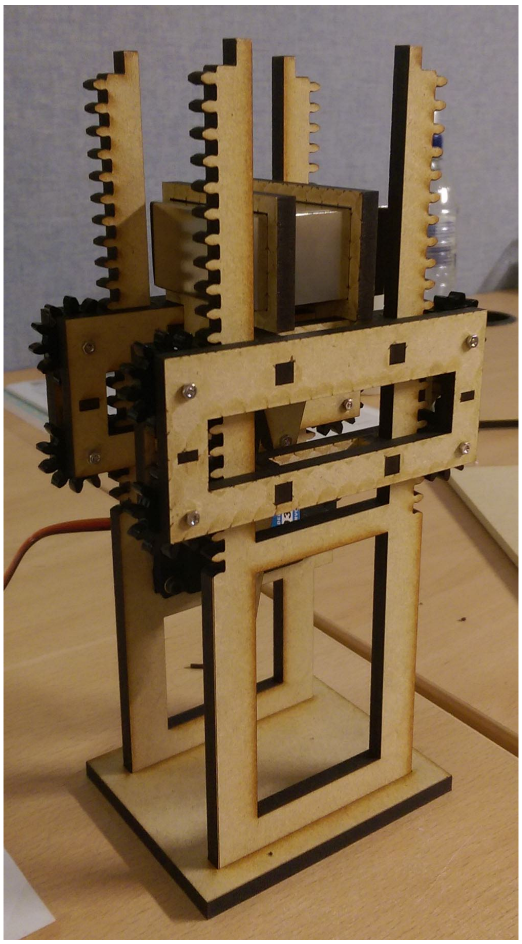

Figure 3.33: Constructed Final Prototype

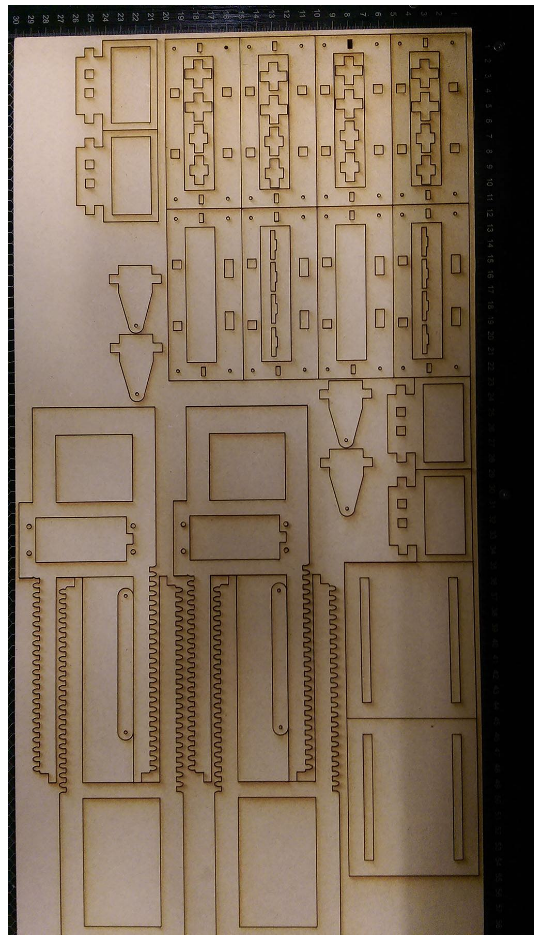

Figure 3.34: Laser Cutter Design of the Final Prototype

Figure 3.35: Custom Built Glass Dome

The original intention was to 3D print the map in sections and piece together, with fewer parts needing to be combined, however the ferro fluid leaked out of these 3D printed models. They also took a long time to print, meaning that any mistakes cost a lot of time and the finished look was a little messy.

Subsequently laser cutting was used, which allowed for fast prototyping, the option to engrave, a large variety of readily available colours and created a neat and professional finish. The physical map of Bristol created also looked similar to the image used to create the GUI.

The RFID tags were embedded into laser cut disks which formed the tangible aspect of the display, see figure 3.37. These disks used wood and clear acrylic to give a warm feel. They also contained an inscription and image relating to the dataset that each disk represented. As discussed in the research, Shaer & Hornecker (2010) stipulate that tangible objects should be representative of content themselves to allow users to better engage with the interface.

The mechanism connecting the tops of each tower with the laser cut ward was also able to rotate, meaning that regardless of the tower's position the area on the top can be moved into the required position, see figure 3.40 and 3.41. This became particularly important because a couple of the vacuum forms containing the ferrofluid were slightly off center, but by rotating them the effect of the magnets was kept uniform.

In order to create the visual effect desired from the ferrofluid, without increasing the size

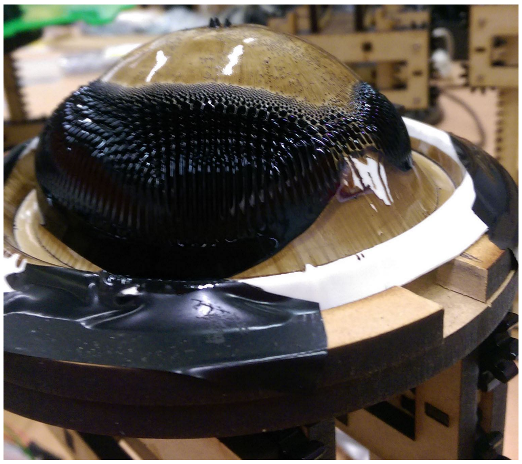

Figure 3.36: Wrong Dome Size

Figure 3.37: Final RFID tag design

of the map too much, 20ml of ferrofluid was used for each Bristol ward. The weight of this much ferrofluid meant that at a distance of around 10cm the ferrofluid was not visually responsive and as the magnet got closer there was enough fluid to make the visualisation appropriately dramatic.

Variable Magnetic Fields

The mechanism used to create the variable magnetic field was created in discussion with engineers and physicists using various tools, such as magnetic field sensors, in order to make sure it could provide the range of movement required whilst securely holding the magnets, which were very strong. The magnets needed to be at least 15cm away from other magnets, slightly less was feasible when they were securely fixed to their towers (approx. 12cm), which was ensured by the map design.

A magnetic field sensor was used to determine the magnetic field generated by the magnets. They rated at 0.5 Tesla on the face of the magnets and the field could be detected to a range of around 300mm. However the field strength degraded rapidly as the distance from the magnet increased so it was possible to place the magnets as close as 120mm before the magnets started to attract to each other with any significant force. To be safe a minimum distance of 150mm was kept between the magnets.

At just over 100mm the magnetic field generated by the magnets was weak enough, around 6 milliTesla(mT), to not display any spikes in the volume of ferrofluid used and the magnet stayed at least 25mm from the surface of the ferrofluid at any given time.

(a) Curved Base 1

(b) Curved Base 2

(c) Curved Base 3

Figure 3.38: Images of different data values displayed on the curved base design

Figure 3.39: Tested Dome Models

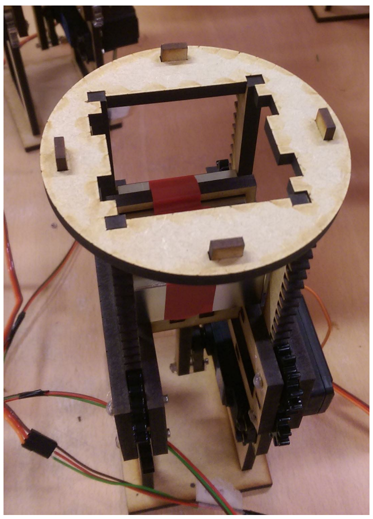

Figure 3.40: Rotating Area Design Part 1

Figure 3.41: Rotating Area Design Part 2

The particular 50x50x25mm neodynium magnets were chosen because they allowed the biggest visual range in the ferrofluid from the magnets that were available. Any bigger and the magnets would have been too difficult and unsafe to handle and any smaller would have compromised the visual effect.

Each tower was laser cut, mostly, out of 6mm MDF, with the exception of the cogs which were cut from 5mm acrylic. The MDF proved to be much more sturdy than the acrylic, especially for the longer rods. The cogs were made from the thinner plastic to reduce friction and allow them to rotate freely within the mechanism. Each tower was press fit together with nuts and bolts holding the moving parts in place.

As the design developed the precision of the build increased, more accurately positioning the components to work together, see an example in figure 3.31. The interface also required less movement of the magnet to give the full visual range of the ferrofluid in each area. This was better for the servo as they drew more current at the extremes of their movement range, which put strain on the circuit.

3.2 The TUI Software

The majority of the software was written in Python to link together and control the hardware components of the TUI. Python was used to allow final implementation of the interface to run on a Raspberry Pi, without the need for larger and more expensive hardware. The program wasn't put directly onto the Arduino because of the space requirements of the data. In addition any changes or updates can be made directly through the Raspberry Pi whereas an Arduino needs to be connected to an external computer to be updated.

The Python program uses two Arduinos, one for input (RFID reader) and one for output (servo motors). These boards are plugged into the computer running the Python program. Each Arduino runs a program written in Arduino's subset of C++ which communicates with the main Python program through a Serial API.

The Python program was used to read and interpret the data from JSON files, taken from Bristol City Council's open data website. The program read information from an RFID reader through an Arduino and this information was interpreted by the Python program which assigned the correct values from the JSON file to a dictionary of area values which were communicated to the servos, which moved accordingly.

Because the visualisation created by the ferrofluid had a non-linear correlation to the position of the magnet, controlled by the movement of the servo, the data value was interpreted by a function that assigned appropriate servo positions for each area. This function was developed by plotting the servo position against the perceived percentage value at every tenth percentile. This was then translated to a graph of servo position against actual data values, see figure 3.42. The function in blue was the closest fitting function, to the observed data, according to a sum of squares test. This involved calculating the sum of the squares of the differences between the observed data and that produced by the function and adjusting variables in the best fit function until the smallest sum of the squares was found.

The equation found from this method was:

$$p = 140 - 1.7d + 0.009d^2$$

p = position of the servo

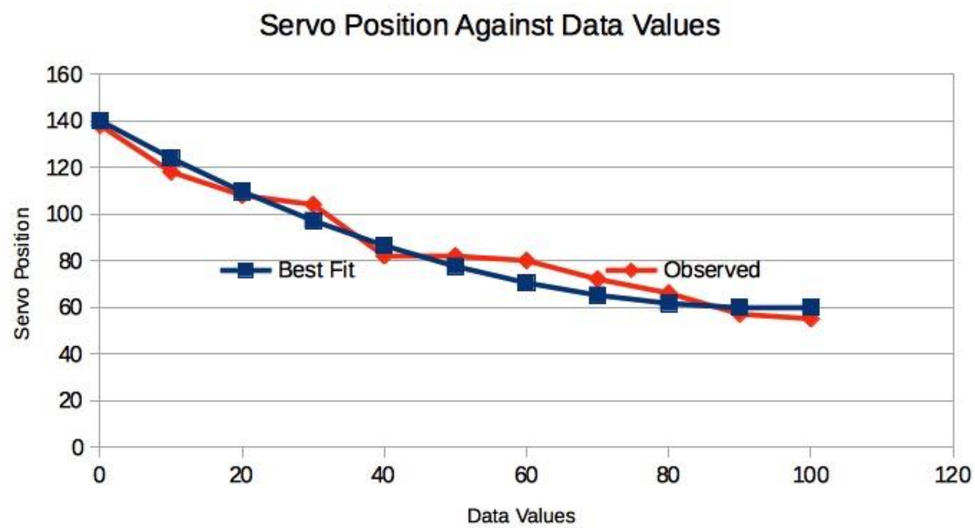

Figure 3.42: Graph plotting the observed data values against a function giving the best fit to that data.

d = value of actual data

A function was added to the software after initial user testing which meant the servos only moved if a new RFID tag was read. This was done because users would place the tag on the reader and leave it there which caused the servos to move to where they already were repeatedly. Whilst this wasn't a particular problem, it used more power and was a concern in terms of the circuitry that was used.

Whilst developing the TUI there was a need for an accurate way to position the servos at will. A program was written to allow user input to control the position of two servos. This was used throughout development in order to control precisely where the servo went to enable calibration and testing of each prototype that was separate to the final program, see figure 3.43.

3.3 Developing the GUI

The GUI was written in Java and used the same image that the map areas for the TUI were modelled from. Users chose the dataset they wanted to see by clicking on the appropriate button representing that dataset. Black circles were used in the center of each ward to represent the data. The radius of these circles would increase or decrease in correlation to

Figure 3.43: Initial program used to control the servos

the data.

The main class written, Map.java, contains easy access to the datasets to allow for changes in the data without having to find specific parts of the code.

When the program is run the 14 combined wards of Bristol are made into Area objects and stored in an array. Each Area object contains the name, location and radius (referring to the data to be represented in that area) of the object it is representing. Each Area object is constructed and given just a name, which refers to a particular Bristol ward, however immediately after creating the array of Areas a setLocations() function is called which loops through the array and applies specific locations to each of the area objects, which refers to the center of that area's position on the visual map. This is done manually through the use of a switch statement. This makes sure that all permanent data about the areas is set before any interaction takes place.

When a button is clicked, the program parses the chosen data from the data file and the radius of each area in the Areas array is updated with a new value corresponding to the data chosen by the user.

The Map Areas are drawn, and updated, through the Drawing class, and the Description class is used to draw the buttons and description to the left of the screen.The Description class is used once and the left part of the screen remains the same for the duration of the program running.

This software was developed in order to give a comparative model of data representation to the TUI for users to evaluate. Like Horn et al. I was "careful to make the visual and the tangible...as similar as possible"(Horn et al., 2009, p. 4). It was important that the users could see a similarity in the two interfaces and that both interfaces were approaching the problem in a similar way. The GUI also confirmed that the TUI was representing data accurately.

See an image of the final GUI in figure 4.3.

3.4 Evaluating the Interfaces

3.4.1 Similar Research

Horn et al. (2009) compares the engagement of tangible over graphical user interfaces. They set up the two interfaces next to each other, see figure 3.44, and record users' interactions with each. Sindorf et al. (2015) looks to make similar comparisons, but chooses to alternate which display is available to use throughout the day, so only one interface is available at a given time. Due to time constraints this project chose the former method to measure user engagement with the interface. These findings were compared with the results of the two studies mentioned.

Figure 3.44: Robot Park exhibit, Boston Museum of Science

3.4.2 Evaluating the use of computer science

From the research conduction a formal method of evaluating TUIs, could not be found. The project instead used a combination of informal observation of passive engagement and responses taken from UX software for both the graphical and tangible interface, as outlined below. Part of the evaluation also assessed the technical aspects of the project, particularly how the technologies performed, along with improvements that could be made to aid any future work in this project area.

Qualitative methods were necessary for evaluating the success of the project, since the main focus was on human computer interaction and users' engagement. Vissers & Geerts (2014), take steps towards establishing a qualitative method to evaluate the user experience (UX) of TUIs. They discuss the need for evaluation methods that focus on what Read, Sheehan & Xu (2008) call 'Tangible Magic', which is described as "the novelty of seeing objects that would normally be regarded as inanimate, doing unexpected things" combined with "the almost indefinable pleasure we receive in handling physical objects". (Read, Sheehan & Xu, 2008, p. 98) These papers, however, do not offer suggestions as to how you might conduct an effective evaluation of the user's experience of a TUI, only evidence to suggest that one is needed.

The area of UX can be very subjective, since it is based on individual's experiences of a product and is not always directly related to the product's functionality and design. Provost & Robert (2013) suggest the use of a 'UX Evaluation Grid' to help identify which areas of the product contributed to both positive and negative experiences.

> "Subjects first had to read the grid that included a short definition of the nine following dimensions: functional, informational, perceptual, physical, cognitive, psychological, social, contextual, and temporal. Subject had to indicate on a scale of 0 to 5 if each of the dimensions had contributed to make his/her experience positive (0= no contribution; 5= great contribution). The exercise was repeated for the negative experience using a scale of 0 to -5. For each rating, subjects were encouraged to briefly justify the scores." (Provost & Robert, 2013, p. 403)

To get a more accurate reflection on user experience, the project chose to use existing evaluation software called AttrakDiff. This software allows users to select how they feel using the interfaces by selecting an option on a scale between two word pairs, see figure 3.45. This approach removed bias, as Hassenzahl expressed "A poet may find beautiful words to describe her experience, this does not make it superior to what more mundane people experience."(Hassenzahl, 2008, p. 4)

AttrakDiff was also used by Bargas-Avila & Hornbk (2011) who identify the dichotomy of UX dimensions and the difficulty this leaves for UX evaluations. They used the software to avoid introducing a new method of evaluation and thus the risk of "ending up with an endless number of words that describe similar phenomena within UX." (Bargas-Avila & Hornbk, 2011, p. 8)

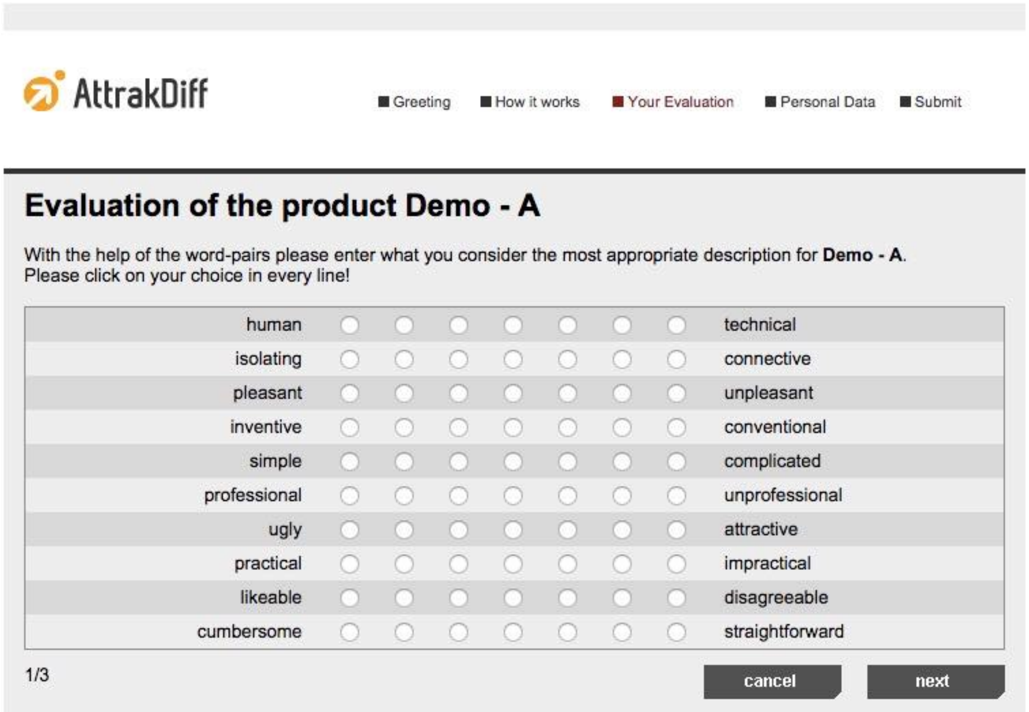

Figure 3.45: Example Users View of AttrakDiff Evaluation Software

The responses collected were broken down and comparisons were made between the GUI and TUI, and also with research from Sindorf et al. (2015) and Horn et al. (2009). The former was used to identify if the TUI facilitates an increase in engagement and the latter should help position the work of this project in the wider field of TUI research.

3.5 User testing

3.5.1 Principles of good user testing

Hassenzahl (2008), identifies a key concern of HCI in adapting technology to human nature. He boils UX down to a series of momentary evaluative feelings related to human-product interaction. UX can have pragmatic or hedonic qualities. Pragmatic quality refers to the product's ability to complete potential tasks, whereas hedonic qualities allow the user to relate to the product and contributes directly to the user's positive, or otherwise, experience. The hedonic qualities are taken from characteristics of core human need, for example "being competent" and "being related to others". These emotions need to be stimulated by a product to provide good UX and ultimately a positive human-product interaction.

Hassenzahl also critiques how the current model of UX evaluation is focussed only on the pragmatic qualities, examining how well a product performs a particular task, rather than on how the user feels as that task is being carried out, an observation echoed by Bargas-Avila & Hornbk (2011).

From his research, Hassenzahl and others created the AttrakDiff software to holistically evaluate users' experience of products. The software covers pragmatic, hedonic and attractiveness qualities of the product being evaluated. The hedonic aspect was an important component to the design of the TUI, as it was important that the interface allowed users to make a connection with the data it was representing and hopefully left an impression.

3.5.2 User testing in this project

User testing took place in two phases. The first phase consisted of two pilot studies with a selection of participants who were asked both general and specific questions about various aspects of the TUI, in order to better develop interface components. Some responses required work outside the scope of this project, discussed in the future work section.

In the first pilot study the full interface (map) was set up in a public space without any ferrofluid or interaction. As people passed, they were asked general questions about the purpose of the interface. The users were also asked whether this implementation might be appealing or not for the specific purposes of engaging people with open data.

The second pilot study focussed on the interpretation of the data and asked users how they interpreted data values displayed on single areas of the interface using the ferro fluid.

A second phase looked at a more formal evaluation of the user experience of the TUI compared with using a similar GUI interface, using the AttrakDiff software. The survey gave each user a number of word pairs and let the user choose a point on a scale between them to best describe their experience, see figure 4.4. 15 participants used both the TUI and the GUI in turn as the interfaces were placed next to each other, see figure 3.46.

Figure 3.46: Both interfaces set up for formal user evaluations

Chapter 4

Results

4.1 Final TUI and GUI

The main outcomes of the project were:

- A tangible user interface, see figure 4.1 and 4.2.
- A graphical user interface, see figure 4.3.
- Pilot tests for the development of the interface.
- A comparative user experience study of both interfaces.

4.2 Results of the Pilot Tests

The first two pilot studies contributed informally recorded comments and actions which helped with the development of the TUI and identified future considerations for further work. Similar actions and comments were distilled into a central list.

Comments about the data:

- Types of data to display could include: number of tweets, polling data, traffic information
- It is clear that the data would be about Bristol.

Comments about the interface:

- Due to the combination of wards, some people expressed a desire for a more specific map interface so they could identify where they lived more easily.

Figure 4.1: Side view of full TUI

Figure 4.2: Top view of full TUI

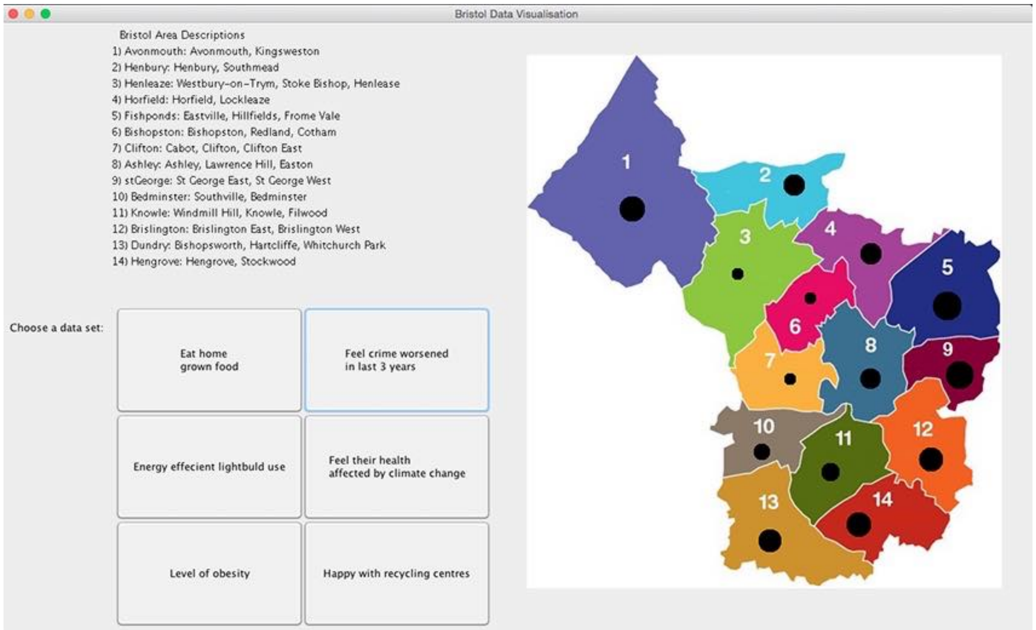

Figure 4.3: Graphical User Interface

- "Does it move?"
- People were not sure what the disks were for (tags for selecting data sets).
- "It looks good!"
- A significant proportion of people touched the black circles and were intrigued by them.

It was noted people needed a point of reference in order for their interpretation of the ferrofluid to have significant meaning. As Einstein (1905) talks about in his special theory of relativity, there is no absolute point in the universe and for anything to be meaningful you need a point of reference. This observation resulted in the decision to include states where all areas could be set to 0% or 100%. For the purposes of the prototype these two states have to be deliberately chosen and was manually demonstrated to the users for the purposes of the evaluation. If developed further, this feature could be integrated into the core workings of the interface so that outside interactions were not needed to help users interpret the data values.

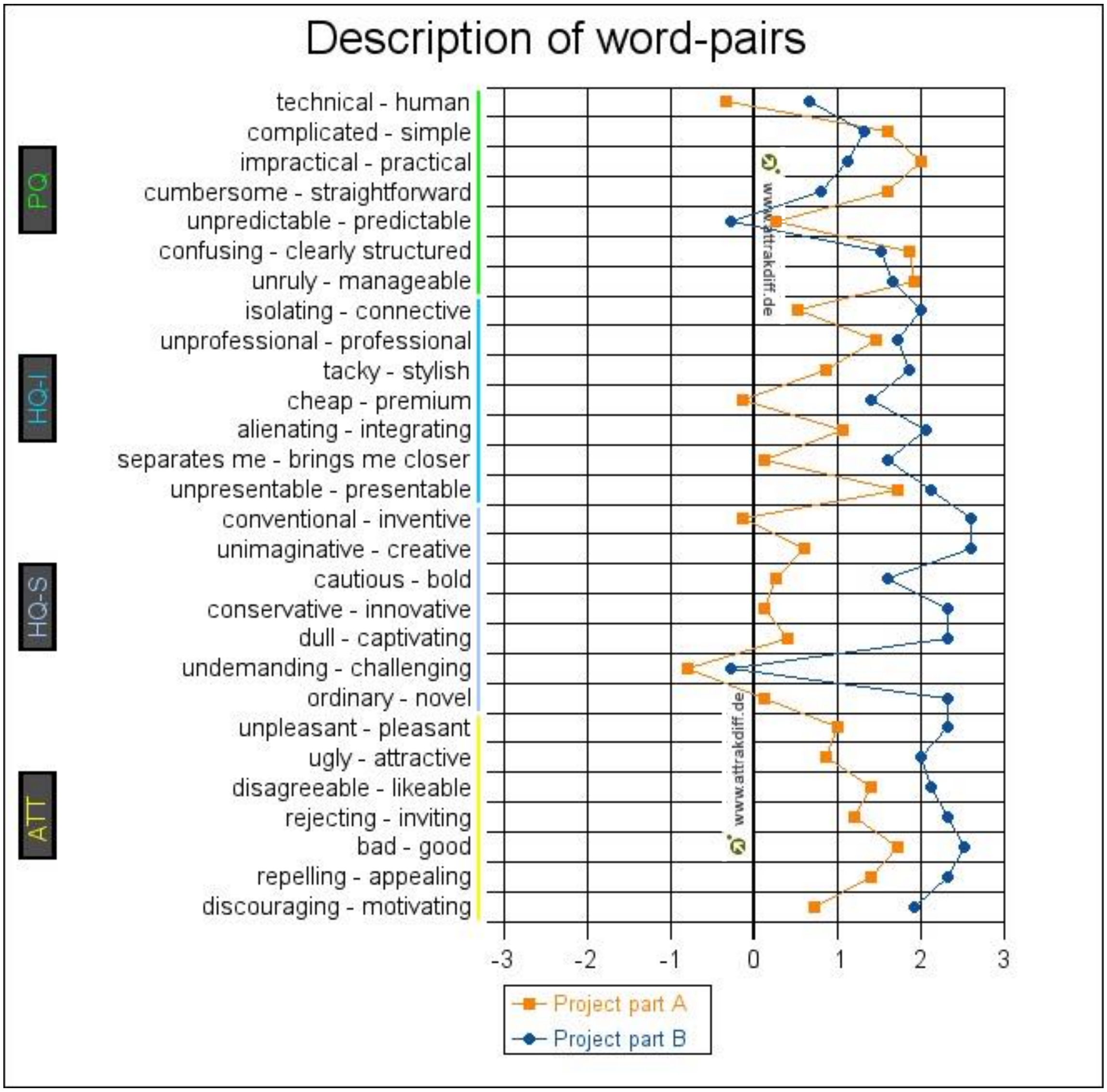

Figure 4.4: Results of word pair anaysis. Part A: GUI, Part B: TUI

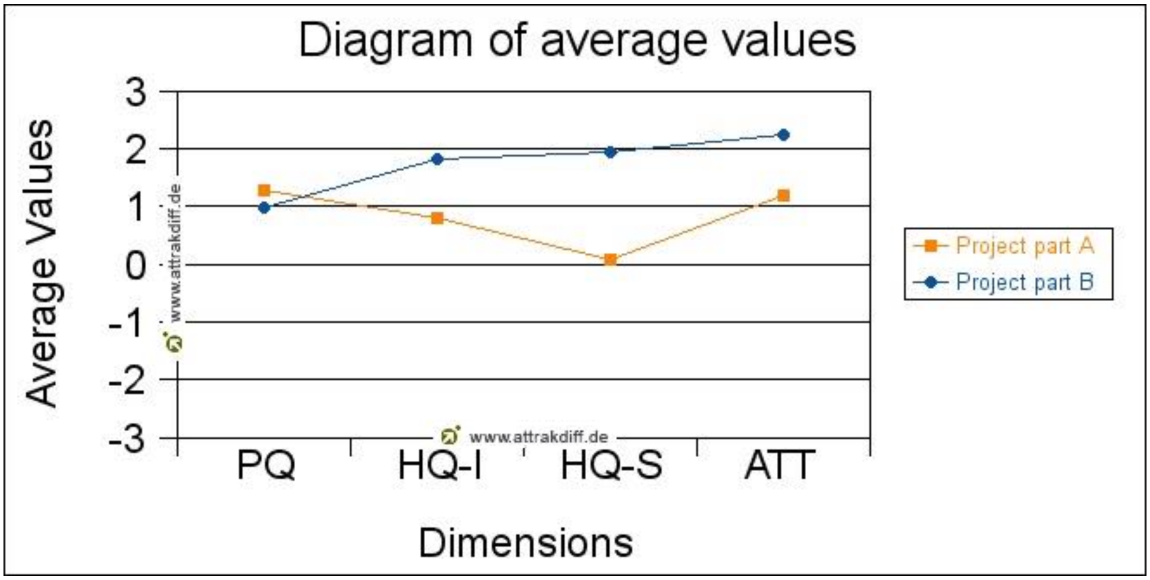

Figure 4.5: Average values for the four assessed qualities. Part A: GUI, Part B: TUI

4.3 AttrakDiff Results

Participants used both interfaces and were given questionnaires to complete using AttrakDiff, described above. The surveys were carried out separately for each interface and a comparison was made later using a combination of the users' feedback for each interface.

The word pairs were split into four categories. Pragmatic qualities (PQ) referred to the usability of the interface and how successful the users felt in achieving their aims. Hedonic qualities (HQ) were split into stimulation (HQ-S), which refers to how novel and interesting the interface is including interaction and presentation style, and identity (HQ-I), which refers to the extent in which a user can identify with the interface. Finally Attractiveness (ATT) describes a global value of attractiveness based on the user's perception of the interface's quality.

The results from the users word pair choices were combined in a comparative graph, see figure 4.4. These are the results of 15 test participants, using both the GUI and the TUI, see figure 3.46.

Pragmatic Qualities, PQ: In terms of pragmatic quality, both interfaces required improvement to be at an optimum level. The GUI scored higher in most areas comparing pragmatic qualities giving in a higher overall pragmatic rating. It scored significantly higher in the simple, practical and straightforward categories, which came as no surprise, since the interface will feel more comfortable and familiar to most users. The difference between the pragmatic qualities however was not statistically significant.

Hedonic Qualities, HQ-I: The responses were significantly higher for the TUI, which added to its perceived Hedonic value. The specific factors, addressing the level to which the users felt they could identify with it, demonstrated the same values that Clarke et al. (2014) discussed when talking about 'socially engaged arts practices in HCI'. This acknowledged both the aesthetic as well as the technical aspects involved in the development of the TUI.

Hedonic Qualities, HQ-S: This category, whilst receiving a similar rating to HQ-I, experienced the biggest contrast between the two interfaces. The majority of the factors contained in the assessment of HQ-S were innovative, creative and bold, all characteristics people give to things that they are excited about and might not have seen before. It is this category that most closely describes the characteristics that the TUI was aiming to possess and it is the contrast in users' responses to the TUI and GUI in this category that give the most weighted evidence supporting a successful outcome of this project.

Attractiveness Qualities, ATT: This category was not one that was directly answering the aim of this project, however the positive results gained from this category help provide evidence to the engaging qualities of the interface and if further evaluation was carried out like Sindorf et al. (2015), the attractiveness qualities would be an important factor.

Statistical significance of this information was also calculated using a 5% significance level. The results indicate that whilst the GUI has a higher pragmatic rating than the TUI, this is not statistically significant and cannot be taken as a characteristic that the whole population would agree with. The results of the hedonic characteristics were statistically significant. Since the TUI scored more highly in these areas, it can be inferred that the results from these characteristics would be reflective of the population as a whole. You can see the difference in the average values for each of the four characteristics assessed in figure 4.5.

Chapter 5

Evaluation

An evaluation was carried out in comparison with two similar studies, which also compared the use of a TUI to a GUI, and also in relation to the aim and objectives determined at the outset of the project. Both sections refer to the results recorded from the pilot studies and formal UX evaluation.

5.1 Comparison of Results with Other Studies

Horn et al. (2009) carried out a study in a museum where a tangible and a graphical user interface were placed side by side, see figure 3.44, and interaction with both was observed informally. In contrast, Sindorf et al. (2015) presented two separate interfaces (graphical and tangible) on different days, so a different set of people evaluated each. For the data gathered, Sindorf et al. (2015) used the same significance level (5%) as this project to assess their results and Horn et al. used a combination of 5% and 1% significance levels in their assessment.

Though the evaluation carried out by this project differs in format from these studies (using formal as well as informal feedback) it is looking to answer similar questions. Thus the the key questions assessed by these studies will be used as a benchmark for evaluating the project results. Highlighted questions will be in **bold** followed by reviews from the two research papers and from this project.

Were visitors more engaged with the TUI than the GUI?
Both Horn et al. (2009) and Sindorf et al.(2015) found an increase in user engagement for the tangible as opposed to the graphical user interfaces using only observational data to assess engagement, a result that backs up the findings of this project.

This project evaluated this question through the AttrakDiff questionaire, which highlighted statistically significant results in the hedonic categories, which would indicate that users found the TUI more engaging. Observed test participants spent significantly less time testing the GUI as they did the TUI. The results indicated that users considered the TUI novel and captivating, as evidenced by their prolonged interaction. In some cases it was difficult to get the users to interact with the GUI at all.

Did the TUI afford better social interaction?
For both studies, this was commented on as a contributing factor in the overall engagement of the interface. Horn et al. (2009) observe that "for engagement, the type of interface might be less important than actively involving multiple participants." (Horn et al., 2009, p. 7) Sindorf et al. (2015) suggest that developers of "tabletop exhibits may consider using TUIs to foster manipulation or encourage group use." (Sindorf et al., 2015, p.39)

This question was considered separately from engagement, because group interaction wasn't officially evaluated in this project. However, when the partial TUI was on display during a poster presentation and a university open day it drew the attention of groups. Several individuals gathered their friends to observe and play with the interface. These interactions did last longer than the interactions of individuals but were only informally observed.

Was the TUI better at fostering inquiry?
Horn et al. (2009) comment that the tangible interface enabled children using the exhibit to be more inquisitive. They considered not only from the length of time children spent at the exhibit, but the types of comments and questions the children asked whilst using each type of interface. Sindorf et al. (2015) found that there was no significant difference between the level of inquiry displayed by the users of either the graphical or the tangible interface.

The project found that users expressed the opinion that the TUI was more motivating than the GUI. More investigation of the data was made through the TUI and many questions asked. However, unlike Sindorf et al. (2015), both interfaces were always available and the users usually chose to explore the data through the TUI because it was more interesting. If the interfaces were made available independently of each other the option to choose would be removed and the same inquisitiveness could be generated from both.

Does the TUI lead to better understanding?
Horn et al. (2009) conclude that there was no significant difference between the understanding taken from the visual compared with the tangible interface. Sindorf et al. (2015) did not directly address this question in their research, but commented from their investigation in the area of TUIs that there are mixed results when it comes to assessing an increase in the understanding gained from a TUI versus a GUI.

This project found that users had a better understanding of the data when observed through the GUI, but this finding was not considered statistically significant.

Are people drawn to engage with the exhibit more through the TUI?
This was the main focus of Sindorf et al. (2015) who, by allowing the two interfaces to be available separately and over prolonged periods of time could assess which interface, if any, attracted more people to look at the exhibit. Their findings suggest that people are drawn more to the TUI than the GUI, but because the TUI lead to longer interaction they were unsure if it was people already interacting with the interface that drew others to look at it or if it was the interface itself.

During the presentation of the TUI in a room full of other GUI software, the TUI drew groups and individuals to come and enquire about what it did and request if they could have a go. Whilst this is not concrete evidence, the results of the survey suggest that the TUI is significantly more attractive and it could be inferred that it would draw more people to engage with it.

From this assessment we can conclude that the results of the project align with similar research carried out in the comparative study of tangible versus graphical user interfaces.

5.2 Aims and Objectives

This section evaluates to what extent the project achieved the stated aims through the objectives defined at the outset of the project.

Aim: To evaluate whether a tangible user interface could engage and excite democratically excluded audiences with open data, bridging the gap between open data and the people using it.

Objective 1: Carry out research of current literature relating to both open data and methods of human computer interaction (HCI).
The background and context section of this report fulfilled this objective by identifying the gap in current research for a bridge to make open data usable for ordinary people. Current HCI literature informed the direction of the project through the recommendation of a TUI to resolve this issue. Good practice was referred to throughout the design and evaluation and some research was carried out during implementation in order to effectively evaluate the interfaces.

Objective 2: Create a playful, tangible user interface (TUI) able to represent selected sets of open data.

- *The data should be represented directly and ensure no bias or misrepresentation*
- *The interface should require no specialist skills to operate or interpret the data shown on the interface. It will be important that any tangible interaction is intuitive and easy to understand. The TUI should not be a barrier, but a conduit, to the data it is representing.*

This objective was fulfilled by a final implementation of this interface, see figure 3.10. The playfulness of this interface was confirmed through users from the formal evaluation, pilot studies and the poster presentation.

A function was written to represent the data in a linear fashion with the ferrofluid. 0% and 100% were represented in order for users to see the relative difference in their chosen data values. This ensured the data was directly represented. The representation of the data was confirmed by one test participant who was "surprised that the data could be represented to such a similar accuracy as on the GUI".

Some clarification was needed to inform the users what the interface did, but once the users had observed it being used, as the interaction is very simple, they managed operate the interface without difficulty. Similar instruction was needed for the GUI.

Create a graphical user interface (GUI) similar to the TUI.
A graphical user interface was created, see figure 4.3. As described above, this GUI was created to display data in a comparative way to the TUI in order to allow accurate user testing. The TUI was designed to reflect the GUI in design, shape and comparative representation, meaning this objective was fulfilled.

Carry out an evaluation of the TUI, alongside a comparative assessment of the GUI, to provide evidence that it improves users' engagement with open data
This objective was fulfilled through the results of the project. The TUI went through two pilot tests and the GUI and TUI were assessed through a user experience (UX) study. The pilot tests were informal and helped further development of the TUI prototype. The formal user experience study highlighted the preferred hedonic value of the TUI. In particular people found the TUI to be significantly more innovative. Users found that it was a novel interface they had not experienced before and were captivated by it.

Engagement was observed through users playing games of guessing which area might be the highest given a chosen data set. Most users were helped by their familiarity with the Bristol area which led to confirmation or surprise when the data was similar or different to their expectations. This echoes Koeman (2014), who commented that misconceptions or stereotypes are challenged when faced with facts contradicting their opinion. Several users returned to see the interface multiple times, and during the formal evaluations, people wanted to continue engaging with the TUI and were unwilling to spend any longer than needed testing the GUI.

Building on the work, above, that has been completed, consider ideas about future work in this area.
Please see the following chapter for an outline of proposed future work coming from this project that was generated through the research and the implementation of the project itself.

Overall, in reference to the main aim, this project has been a success. A TUI has been created that performs well. Whilst the user testing only included a couple of people from the target audience, the significance of the results attained would indicate that further work and development of a ferrofluid based TUI interface for displaying open data would be beneficial and would increase engagement with open data for the general population. Also, due to the easy usability of the TUI, accessibility of open data for democratically excluded audiences would be increased.

5.3 Highlights

This project involved a large number of academic disciplines, art and design, physics, geography, engineering (design and electrical) and computer science. As an expert in just one of these fields, the project involved a steep learning curve and a host of interactions with various researchers, academics and technical staff. Whilst this was a challenge, I thoroughly enjoyed learning different skills and seeing computer science act as a glue between this wide array of fields.

The final TUI created through this project was very pleasing and it was more impressive than seemed possible after the first prototype. The unexpected movement of the ferrofluid was fun to play with and very visually striking. The UX test results contained the positive responses of people using the interface who were seeing the ferrofluid for the first time in this context, or at all.

5.4 Challenges

5.4.1 Challenges in implementation

Some skills needed for the project were easier to learn than others. One of the biggest problems encountered was the electronic circuit required to power the servo motors. Initial development only required one (at most two) servo(s). The basic circuit was simple and

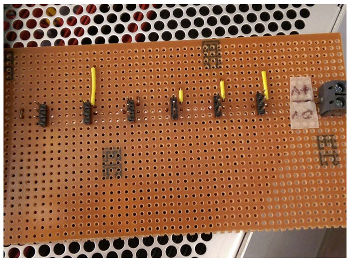

Figure 5.1: Designed Circuit Front

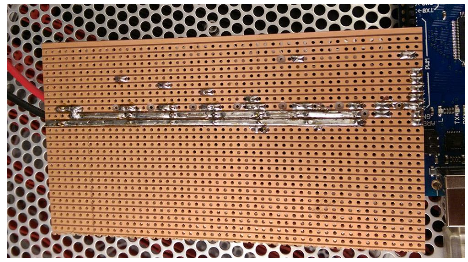

Figure 5.2: Designed Circuit Back

the current needed to power one servo was relatively small and consistent. However, once the full interface began to take form, more servos were added, which started to overheat the circuit. A circuit board was developed through speaking to an electrical engineer, see figure 5.1 and 5.2. This caused the servos to act erratically due to the servos not being grounded properly. There was not sufficient time to redesign the circuit-board and the final interface was built from several smaller circuits to reduce the current requirements. The interface was switched on only for short bursts when users chose a new dataset and then switched off in-between. This would be an important consideration for future prototyping of this kind.

Another challenge was the display of ferrofluid. One factor in trying so many ways to present the ferrofluid was the unfamiliar nature of the liquid. Nobody mentioned in research had used the liquid for these purposes and there was little advice about how it should be displayed. When the containers didn't work the ferrofluid was very messy, and this went through a number of designs before a suitable one was found.

One further concern was the strength of the magnets that were eventually used in the display. The magnets were about half a Tesla on the surface and posed difficulties in working out where to store them and how to display them. Fortunately there were no major incidents, but two of the magnets are now permanently stuck together.

5.4.2 Challenges in evaluation

One challenge became apparent during the evaluation. A couple of the test participants didn't understand what some of the word pairs meant (i.e. Human - Technical), I realised that this could be unclear and if the project was taken further, more detailed instructions would be needed. A structure could be used similar to the user experience study carried out by Provost & Robert (2013), where they gave the users a grid to read before the evaluation which contained the definitions of each element and an opportunity to ask questions about the evaluation itself.

Additionally, the two users who would potentially fall into the target audience of this project found it more difficult and confusing to access and complete the AttrakDiff survey than they did using the two interfaces. As I knew these people, I was able to talk them through it, however if this project was to carry out an evaluation with the target audience it would be worth spending time directly after the users had tested it to access the survey for them and let them complete it whilst somebody is there to help.

Chapter 6

Future Work and Conclusion

6.1 Conclusion

This project looked at the current problems around public engagement with and interpretation of open data. From background research (see chapter 2), it was established that open data has high potential social and economic impact, but though provision of open data from governments and organisations is good and increasing, the general public are mostly unaware of the existence of open data or lack the skills to use and interpret it.

The project provided an overview of research in the areas of open data and human computer interaction (see chapter 2) and found there to be a missing bridge between these two fields. This project produced a novel tangible user interface (TUI) to provide this 'bridge' by increasing users' engagement and ability to interact with and interpret open data. The TUI produced in this project, as far as my research found, has never been implemented before (see chapter 3).

A graphical user interface (GUI) was also built, as a more conventional method of data visualisation, in order to comparatively evaluate the impact of the TUI, see chapters 4 & 5.

Evaluation was carried out through two informal pilot studies and a formal user experience study of 15 participants, using a program called AttrakDiff. The conclusion was that users are more attracted to and prefer using the TUI over the GUl. The pragmatic qualities of the two interfaces were similar, if not slightly better for the GUI, however the difference was not considered statistically significant. Since the aim was to increase engagement, this was a successful outcome.

The project demonstrated that a TUI could increase engagement with open data over more conventional methods such as a GUI. However the interface prototype would need more work to implement in the settings that would allow for the target audience, those unfamiliar with using computers or assessing statistics, to use it.

6.2 Suggestions for Future Work

Suggestions for taking this work further include those could not be implemented within the time frame or were considered outside the scope of this project.

6.2.1 From the Research

The field of tangible user interfaces for open data and data in general is relatively untouched, in comparison with, for example, the field of tangible interfaces to help with learning. Further development of new TUIs that display and therefore increase the use of available open data would have great value to the growing number of people, agencies and governments that are campaigning for the release and effective use of this data.

6.2.2 From the Pilot Study

As mentioned previously a significant proportion of test participants expressed an interest in being able to touch the ferrofluid. Under the limited time and resources allocated it was not possible to act on this feedback. However from the users' responses to the interface it was clear that this would add to the user experience.

This project worked with open data from Bristol City Council in order to communicate relevant data to the population. Further work with this interactive map idea could experiment with using different data sources. As mentioned above, Twitter and traffic information would be interesting to people, however relevancy should be considered as traffic information is irrelevant to people who are not driving / using the roads and Twitter information would be meaningless to some groups of people.

6.2.3 From the Results and Evaluation

The data represented by the TUI was not meant to be a precise representation of open data, but a method of making comparisons between areas and to engage people not normally interested in data. An area of further work would be to look at how you might use the ferrofluid to display data more accurately.

A specific area for further work around this TUI would be the ability for the user to query the data for specific information, e.g. a direct comparison of user-specified content. Some users expressed an interest in exploring the data further, an easy way to do this would be to add a way for the data representation to be switched from displaying the raw data, as it does currently, to displaying each dataset so that the area with the smallest data values would be set to zero, the largest to one hundred and the other values spread between those respectively.

Chapter 7

Bibliography

Bargas-Avila, J. A. & Hornbk, K. (2011). Old Wine in New Bottles or Novel Challenges ? A Critical Analysis of Empirical Studies of User Experience. Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, 26892698.
Benyon, D. (2010). Designing interactive systems A comprehensive guide to HCI and interaction design. Edinburgh: Pearson Education Limited.

Berners-Lee, T. (2010). The year open data went worldwide. [Online Video]. Available from: http://www.ted.com/talks/tim_ berners_ lee_ the_ year_ open_ data_ went_ worldwide?languageēn. [Accessed: 02 April 2015].

Carroll, J. M. (2013). Human computer interaction-brief intro. The Encyclopedia of Human-Computer Interaction, 2nd Ed. Available from:
https://www.interaction design.org/encyclopedia/human_ computer_ interaction_ hci.html.

Clarke, R. E., Briggs, J., Light, A., Heitlinger, S., & Crivellaro, C. (2014). Socially engaged arts practice in HCI. In CHI'14 Extended Abstracts on Human Factors in Computing Systems, pp. 69-74. ACM.

Davies, T. (2015). Open Data Barometer-Global Report, second edition. Available at: www.opendatabarometer.org. [Accessed: 2nd April 2015].

Einstein, A. (1905) On the Electrodynamics of Moving Bodies. In Annalen der Physik. **17**, pp. 891 - 921.

European Commission (n.d.). Digital Agenda for Europe, Open Data.
Available from: http://ec.europa.eu/digital-agenda/en/open-data-0. [Accessed: 22nd April 2015].

Fails, J. A., Druin, A., Guha, M. L., Chipman, G., Simms, S., & Churaman, W. (2005). Child's play: a comparison of desktop and physical interactive environments. In Proceedings of the 2005 conference on Interaction design and children (pp. 48-55). ACM.

Fortin, C., Neustaedter, C., & Hennessy, K. (2014). Posting for community and culture: considerations for the design of interactive digital bulletin boards. In Proceedings of the 32nd annual ACM conference on Human factors in computing systems (pp. 1425-1434). ACM.

Frey, M. (n.d.). SnOil: A Physical Display Based on Ferrofluid. [Online] Available from: http://www.freymartin.de/en/projects/snoil. [Accessed: 18th April 2015].

Hassenzahl, M. (2008). User experience (UX). Proceedings of the 20th International Conference of the Association Francophone dInteraction Homme-Machine on - IHM '08, (September), 11.

Hassenzahl, M. (2010).*Experience Design: Technology for All the Right Reasons*, (s.l.): Morgan and Claypool.

Heng, J. (2011). When sculptures sing through new 3D liquid interface technology. Available from: http://www.eng.nus.edu.sg/ero/announcement/web-liquid01-11-f inal.pdf. [Accessed: 27th April 2015].

Horn, M. S., Solovey, E. T., Crouser, R. J., & Jacob, R. J. (2009). Comparing the use of tangible and graphical programming languages for informal science education. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (pp. 975-984). ACM.

Howto Magnet. (2014) About Ferrofluid. [Online] Available from: http://www.howtomagnet.com/learn-more.html. [Accessed 19th July 2015].

Jaakkola, H., Makinen, T. & Etelaaho, A. (2014) Open Data - Opportunities and Challenges. International Conference on Computer Systems and Technologies. **15**, pp. 25-39.

Karunanayaka, K., Koh, J. T. K. V., Sepulveda, J., & Tharakan, M. J. (2010). Liquid Interfaces: A New Creative Entertainment Technology. International Conference on Digital Interactive Media in Entertainment & Arts. ACE.

Koeman, L. (2014). An exploratory study into the public and situated visualisation of local data in urban communities. In Proceedings of the 2014 companion publication on Designing interactive systems (pp. 173-176). ACM.

Kvasny, L., Kranich, N., & Schement, J. R. (2009). Communities, Learning, and Democracy in the Digital Age. In Learning in Communities (pp. 41-44). Springer London.

Li, S., & Gong, J. (2008). Mashup: A new way of providing web mapping/GIS services. In ISPRS Congress Beijing (pp. 639-649).

Provost, G., & Robert, J. M. (2013). The dimensions of positive and negative user experiences with interactive products. In Design, User Experience, and Usability. Design Philosophy, Methods, and Tools (pp. 399-408). Springer Berlin Heidelberg.

Rawlings, S., & Blake, M. (2013). Using Innovative Technology to Meet the Mandate for Open Data, 15.
Available from: http://pinpoint.microsoft.com/en-US/home. [Accessed 10th April 2015].

Read, J. C., Sheehan, R., & Xu, D., (2008). In search of tangible magic. In Proceedings of the 22nd British HCI Group Annual Conference on People and Computers: Culture, Creativity, Interaction-Volume 2 (pp. 97-100). British Computer Society.

Shaer, O., & Hornecker, E. (2010). Tangible user interfaces: past, present, and future directions. Foundations and Trends in Human-Computer Interaction, 3(12), pp. 1-137.

Shaer, O., & Jacob, R. J. (2009). A specification paradigm for the design and implementation of tangible user interfaces. ACM Transactions on Computer-Human Interaction (TOCHI), 16(4), 20.

Sileika, K., & Skiedrait, I. (2009). Investigation of ferrofluids motion in multi pole electromagnetic field. ULTRAGARSAS Journal, 64(4). Available from http://www.ktu.lt/ultra/journal/pdf_ 64_ 4/Vol. 64 No.4 2009_ 08 Sileika.pdf. [Accessed: 10th April 2015]

Simon, T. M., Thomas, B. H., Smith, R. T., & Smith, M. (2014). Adding input controls and sensors to RFID tags to support dynamic tangible user interfaces. In Proceedings of the 8th International Conference on Tangible, Embedded and Embodied Interaction (pp. 165-172). ACM.

Sindorf, L., Ma, J., Liao, I., & Frazier, J. (2015). Using a Tangible Versus a Multi-touch Graphical User Interface to Support Data Exploration at a Museum Exhibit. In Proceedings of the Ninth International Conference on Tangible, Embedded, and Embodied Interaction (pp. 33-40). ACM.

Vissers, J., & Geerts, D. (2014). Evaluating the User experience of Tangible Interface

Prototypes. In Proceedings of the 8th International Conference on Tangible, Embedded and Embodied Interaction.

Yang, R., Newman, M.W. & Forlizzi, J., 2014. Making sustainability sustainable. Proceedings of the 32nd annual ACM conference on Human factors in computing systems - CHI 14, pp.823 - 832.

Yokokoji, M. & Harwood, G. (2011) Invisible Airs: Database, Expenditure & Power. [Online] Available from: http://yoha.co.uk/invisible. [Accessed: 21st April 2015]

Zuckerman, O., & Gal-Oz, A. (2013). To TUI or not to TUI: Evaluating performance and preference in tangible vs. graphical user interfaces. International Journal of Human-Computer Studies, 71(7), 803-820.

Chapter 8

Appendices

8.1 Apendix A - Code Samples

Listing 8.1: Code which translates data into servo movement

```
#If a valid data set has been passed to the
    function, each servo is moved to its
    respective position
        if check:
            #Starts moving servo in position
                13 on the Arduino board
            count = 1
            for ward in self.wardCombination:
                #Only uses servos between 13
                    and 5 (8 Servos)
                if count < 9:
                    if dataSet == 7:
                        dataValue = 0
                    elif dataSet == 8:
                        dataValue = 100
                    else:
                        dataValue = self.
                            chosenDataValues[
                            ward]

                    print "Initial data", move
                    #code to determine,
                        approximately, the non
                        -linear change in
                        movement of the
                        ferrofluid relative to
                         the servo

                    move = (140 - (1.7*
                        dataValue)) + (0.009 *
                         dataVale * dataValue)


                    move = int(round(move))
                    print ward, ": ", move
                    servo.move(count, move)
                    count += 1
```

Listing 8.2: Code that takes a selected dataset and extracts the data from a JSON file.

```
def setDataValues(self, data, dataString):
        #tempData is just the data section of
            the selected Json file
        tempData = data["data"]
        #Empty array that will be filled with
            the set of chosen data
        chosenData = {}
        self.chosenDataValues = {}

        position = 0
        for i in range(0, len(tempData)):
            #The numbers refer to the array
                position of relevant data in
                the Json file
            if tempData[i][8] == dataString:
                chosenData[tempData[i][10]] =
                    tempData[i][11]

        for ward in self.wardCombination:
            #tempWard is the key value which
                refers to an array of areas
                within that ward
            tempWard = self.wardCombination[
                ward]
            tempValue = 0
            for area in tempWard:
                #print crimeData[area]
                tempValue += int(round(float(
                    chosenData[area])))

            #Divide the total of each area by
                the number of areas to get an
                average
            tempValue = tempValue/len(tempWard
                )
            self.chosenDataValues[ward] =
                tempValue
```

Listing 8.3: Code which reads an RFID tag checks it exists i the program and that it is not the same as the one read previously.

```
# parse the rfid data. rfid data contains
    three values:
        # <number of tags read>, <time in
            milliisconds tag was read>, <tag
            value>
        parsed_rfid_data = shlex.shlex(
            rfid_data, posix=True)
        parsed_rfid_data.whitespace += ','
        parsed_rfid_data.whitespace_split =
            True
        rfid_data_list = list(parsed_rfid_data
            )
        print rfid_data_list

        # using the tag number, lookup the
            corresponding data
        dataSet = translate_tag_to_data_number
            (tag_data_dictionary,
            rfid_data_list[2]);
        print "tag = ", rfid_data_list[2], "
            data = ", dataSet

        # check to see if the 'quit' tag was
            just read and if so stop the
            program
        if dataSet == 0:
          break
        else:
          # ignore the tag if it was the same
              one as the one last read
          if rfid_data_list[2] !=
              previous_rfid_tag:
            dataControl.moveServos(dataSet)
                                  # move the
                servo according to the
                required dataset
            previous_rfid_tag = rfid_data_list
                [2]  # remember what tag was
                just read
```

Listing 8.4: Function that moves specific servos assigned by the user through a graphical interface.

```
def moveServos(self):
        check = True
        stringOne = self.servo1.get()
        stringTwo = self.servo2.get()

        if stringOne.isdigit() and int(
            stringOne) >= 20 and int(stringOne
            ) <= 180:
            servoOne = int(stringOne)
        else:
            check = False
            self.servo1.delete(0, END)
            self.servo1.insert(0, "Incorrect
                Value")

        if stringTwo.isdigit() and int(
            stringTwo) >= 0 and int(stringTwo)
             <= 180:
            servoTwo = int(stringTwo)
        else:
            check = False
            self.servo2.delete(0, END)
            self.servo2.insert(0, "Incorrect
                Value")

        if check:
            servo.move(13, servoOne)
            servo.move(12, servoTwo)
```

8.2 Appendix B - Descriptions of Hardware

This appendix contains information about the specific hardware used in the project.

8.2.1 Servo Motors

Particular Specification

Item No.	CYS-S8203A
Type	Digital
Weight	164g
Size	59.2*29.2*51.3mm
Control System	(+)Pulse Width Control 1500usec Neutral
Required Pulse	
Operating Voltage	6.0~7.2Volts
Operating Temperature Range	(-)20 to +60 degree C
Operating Speed (6.0V)	0.16sec/60° at no load
Operating Speed (7.2V)	0.14sec/60° at no load
Stall Torque (6.0V)	28kg.cm
Stall Torque (7.2V)	30kg.cm
Operating Angle	45deg.one side pulse traveling 500 usec
360 Modifiable	No
Direction	Anticlockwise/Pulse Traveling 1000~2000usec
Current Drain (6.0V)	4mA/idle and 400mA no load operating
Current Drain (7.2V)	5mA/idle and 500mA no load operating
Stall Current	2.3A/2.5A
Dead Band Width	4usec
Motor Type	3 Pole Ferrite Drive
Bearing Type	Dual Ball Bearing
Horn gear spline	17T
Gear Type	Metal
Connector Wire Length	300mm
Wire info	Brown/Black = Negative Red = Positive Orange/White = Signal

Figure 8.1: Fact sheet for the servos used in the project

8.2.2 RFID Reader

RFID Compatibility

The Parallax RFID Card Reader works exclusively with the EM Microelectronics EM4100-family of passive read-only transponder tags. Each transponder tag contains a unique, read-only identifier (one of 2^{40}, or 1,099,511,627,776 possible combinations).

A variety of different tag types and styles exist, with the most popular made available from Parallax.

Connections (Serial)

The Parallax RFID Card Reader Serial version easily interfaces to any host microcontroller using only four connections (VCC, /ENABLE, SOUT, GND).

Pin	Pin Name	Type	Function
1	VCC	P	System power. +5V DC input.
2	/ENABLE	I	Module enable pin. Active LOW digital input. Bring this pin LOW to enable the RFID reader and activate the antenna.
3	SOUT	O	Serial output to host. TTL-level interface, 2400 bps, 8 data bits, no parity, 1 stop bit.
4	GND	G	System ground. Connect to power supply's ground (GND) terminal.

Note: Type: I = Input, O = Output, P = Power, G = Ground

Use the following example circuit for connecting the Parallax RFID Card Reader:

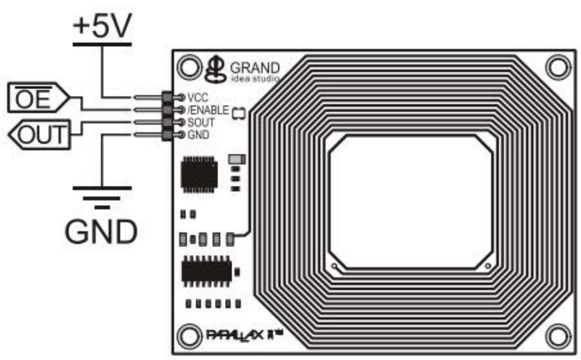

Figure 8.2: RFID reader information

8.2.3 Arduino Boards

Technical specs

Microcontroller	ATmega328P
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limit)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
PWM Digital I/O Pins	6
Analog Input Pins	6
DC Current per I/O Pin	20 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB (ATmega328P) of which 0.5 KB used by bootloader
SRAM	2 KB (ATmega328P)
EEPROM	1 KB (ATmega328P)
Clock Speed	16 MHz
Length	68.6 mm
Width	53.4 mm
Weight	25 g

Figure 8.3: Arduino Uno Specification

Summary

Microcontroller	ATmega1280
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	54 (of which 15 provide PWM output)
Analog Input Pins	16
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	128 KB of which 4 KB used by bootloader
SRAM	8 KB
EEPROM	4 KB
Clock Speed	16 MHz

Figure 8.4: Arduino Mega Specification

8.2.4 Ferrofluid

EFH1 Specifications and Physical Properties

Appearance	Black-brown fluid	
Carrier Liquid	Light Hydrocarbon	
	CGS Units	**SI Units**
Saturation Magnetization (Ms)	440 Gauss	44 mT
Viscosity @27°C	6 cP	6 mPa·s
Density @25°C	1.21 g/cc	1.21 10^3 kg/m^3
Pour Point	-94 °C	-94 °C
Flash Point	92 °C	92 °C
Initial Magnetic Susceptibility	0.21	2.64

Figure 8.5: Information about EFH1 ferrofluid